Generic handbook for assisting in the management of contaminated inhabited areas in Europe following a radiological emergency

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GENERIC HANDBOOK FOR ASSISTING IN THE MANAGEMENT OF CONTAMINATED INHABITED AREAS IN EUROPE FOLLOWING A RADIOLOGICAL EMERGENCY

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For what purpose do I want to use the Inhabited Areas Handbook?

Planning

Go to Section 5 “Planning in advance”

Consider customising handbook for local conditions (e.g. land use) using a stakeholder engagement process

Response

Go to Section 6 “Constructing a management strategy”

Consult decision tree for accident characterisation, monitoring requirements and assessment of doses

Then follow the 8-step process:

Identify surfaces that are likely to be/have been contaminated

Consult selection tables of management options for identified surfaces

Check applicability of management options for identified radionuclides

ELIMINATE OPTIONS

Check key constraints of management options

ELIMINATE OPTIONS

Check effectiveness of management options

ELIMINATE OPTIONS

Check for type and amount of waste produced

Go to Section 3 “Datasheets” for other constraints on the remaining options

ELIMINATE OPTIONS

Select and combine options and build management strategy

Training – new user

Go to all Sections

Section 1 ”Introduction”

Section 2 “Management options”

Section 3 “Datasheets”

Section 4 “Factors influencing implementation of management options”

Section 5 “Planning in advance”

Section 6 “Constructing a management strategy”

Section 7 “Worked examples”

Consult Appendices for supporting information if required

Training – refresher

Go to Section 7 “Worked examples”

This goes through the 8-step process for two examples. A major incident at a nuclear power plant involving ^{137}Cs and a small scale incident involving ^{239}Pu.

1 INTRODUCTION TO THE HANDBOOK FOR INHABITED AREAS

2 MANAGEMENT OPTIONS

3 DATASHEETS OF MANAGEMENT OPTIONS

4 FACTORS INFLUENCING IMPLEMENTATION OF MANAGEMENT OPTIONS

5 PLANNING FOR RECOVERY IN ADVANCE OF AN INCIDENT

6 CONSTRUCTING A MANAGEMENT STRATEGY

7 WORKED EXAMPLES

8 GLOSSARY

CONTENTS OF SECTION 1

1 INTRODUCTION TO THE HANDBOOK FOR INHABITED AREAS

The Handbook for Inhabited Areas or Inhabited Areas Handbook in short, is a tool to support decision-makers in developing a recovery strategy following a radiation incident. The Handbook is a compilation of information to help users identify the important issues and evaluate management options. It has been produced with financial support from the European Commission as part of an integrated project 'EURANOS'. The overall aim of the project is to increase the coherence of emergency preparedness and management in Europe, following accidental or deliberate releases of radionuclides to the environment. This handbook focuses on inhabited areas. Two other complementary handbooks consider contamination of food production systems and drinking water supplies (http://www.euranos.fzk.de). The Inhabited Areas Handbook should be regarded as a living document which requires updating from time to time to remain state-of-the-art.

Contaminated inhabited areas – what's the problem?

Following a radiation incident, contamination may occur in an inhabited area. As a consequence, many types of surfaces and areas could be affected which require specific types of management options to reduce external doses and doses from inhalation of resuspended material. Clean-up may result in large volumes of contaminated material requiring disposal.

How can the Inhabited Areas Handbook help?

The Inhabited Areas Handbook provides decision makers and other stakeholders with guidance on how to manage the many facets of a radiation incident. It contains scientific and technical information on what to do during the emergency, as well as tools to assist in the selection of a recovery strategy taking into account the wide range of influencing factors. The Inhabited Areas Handbook is also helpful for contingency planning.

1.1 Objectives of the Inhabited Areas Handbook

The Inhabited Areas Handbook has been developed to meet several inter-related objectives:

- to provide up-to-date information on management options for reducing the consequences of contamination in an inhabited area
- to outline the many factors that influence the implementation of these options
- to provide guidance on planning for recovery in advance of an incident

- to illustrate how to select and combine management options and hence build a recovery strategy.

The Inhabited Areas Handbook also has a series of secondary aims:

- to generate awareness in emergency preparedness and recovery management options for inhabited areas
- to promote constructive dialogue between all stakeholders
- to identify under non-crisis conditions specific problems that could arise, including the setting up of working groups to find practical solutions
- to elaborate plans and/or frameworks for the management of contaminated inhabited areas at the local, national or regional level.

1.2 Audience

The Inhabited Areas Handbook is specifically targeted at:

- central government departments and agencies
- experts in radiation protection
- local councils and representatives
- water and health authorities
- emergency response personnel (police force, ambulance and fire and rescue services)
- other stakeholders who may be affected/concerned, depending on the situation.

1.3 Application

The Inhabited Areas Handbook can be considered solely as a reference document containing information on scientific, technical and societal aspects relevant to the management of contaminated inhabited areas. However, it is intended that it be used as part of a participatory process in order to realise its full potential. Examples of the most likely applications of the Handbook are:

- in the preparation phase, under non-crisis conditions to engage stakeholders and to develop local, regional and national plans/framework/tools
- in the post-accident phases by local and national stakeholders as part of the decision-aiding process
- for training purposes
- in the preparation for and during emergency exercises.

1.4 Context

The primary focus of the Inhabited Areas Handbook is radiological protection, or, in other words, reducing exposure of humans to radiation. However, experience from past contamination events, particularly the accident at the Chernobyl nuclear power plant, has shown that the consequences of widespread and long-lasting contamination are complex and multi-dimensional. Radiological protection should be considered as only one aspect of the situation. It has been recognised that, to be efficient and sustainable, the management of consequences of radioactive contamination must take into account other dimensions of living conditions, such as economic, social, cultural and ethical issues. Therefore this Handbook also addresses aspects that go beyond those of radiological protection (see Section 4). The handbook is based on the premise that those living and working in the contaminated areas still wish to do so following a nuclear accident or radiological incident. This depends in part on the support provided by the authorities.

1.5 Scope

The sources of contamination considered in the Inhabited Areas Handbook are from a nuclear site or weapons' transport accident. However many of the management options described will also be relevant to other radiation incidents (e.g. an improvised terrorist device) even though the pattern of contamination would be different.

This Handbook only covers the recovery part of the post-accident phase, with a focus on reducing doses from external exposure to radioactive contamination and from inhalation of resuspended material in air. Following a radiological emergency there will be an initial acute emergency phase where urgent measures such as sheltering or evacuation are required to protect individuals from short-term, relatively high risks. The recovery phase should be seen as starting after the incident has been contained; although there are no exact boundaries between the two phases. It continues until agreed recovery criteria have been met. Whilst the Handbook relates only to the recovery phase, it may also be used in the acute phase to provide useful information and advice on the longer-term management of the incident and to look at the implications of early urgent actions on any subsequent recovery strategy.

1.5.1 Topics not covered by the Inhabited Areas Handbook

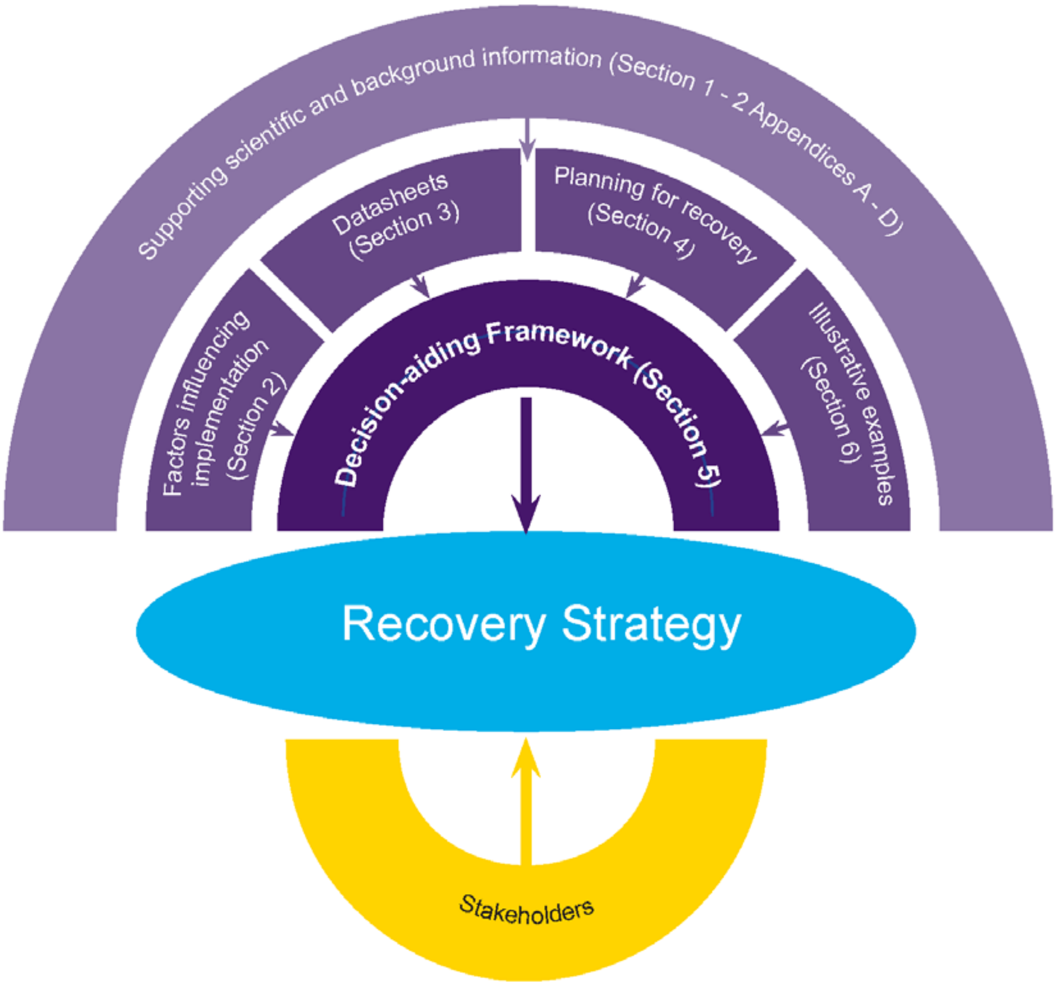
Topics that are not covered by the Inhabited Areas Handbook include:

- guidance for setting up a detailed monitoring scheme
- lists and details of contacts and contractors and the responsibilities of organisations in the event of a radiological emergency
- links between responses at different levels e.g. local, regional
- detailed planning for radiological emergencies including pre-drafted press releases and standard answers
- communication strategy
- wider socio-economic issues of damage, compensation, recovery of business, personal and private losses.

1.6 Structure of the Inhabited Areas Handbook

The overall structure of the Inhabited Areas Handbook is illustrated in Figure 1.1. Section 1 sets the context, scope and audience of the Handbook, its application and describes the importance of various surfaces and hazards in inhabited areas. Section 2 provides an overview of management options for different types of inhabited area; the datasheets for each management option are presented in Section 3. Factors influencing the implementation of management options in contaminated areas are described in Section 4. Information on planning for recovery in advance of an incident is given in Section 5. The main decision aiding framework, including a worked example is included in Section 6 and Section 7, respectively. A detailed glossary can be found in Section 8 and supporting and background information can be found in the Appendices. As noted in Section 1.3, the Inhabited Areas Handbook should be used as part of a participatory process involving local and national stakeholders in the development of a recovery strategy (i.e. lower segment of Figure 1.1).

Figure 1.1 Structure and audience for the Inhabited Areas Handbook



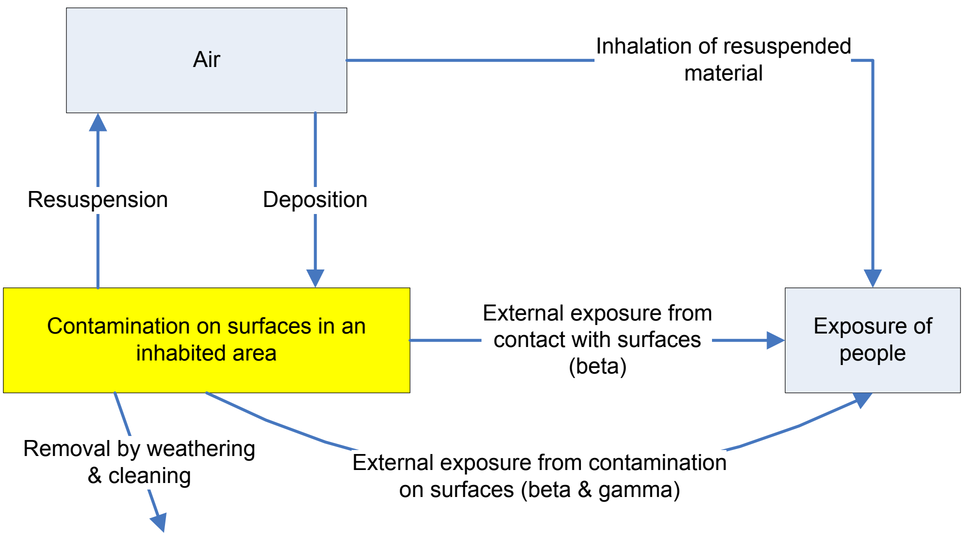
1.7 Types of contaminants, hazards and exposure pathways

Following a radiological incident, health hazards to humans depend on the characteristics of the radionuclides involved and the period of exposure, as well as the distance of the location where people live from the contamination and the presence of any shielding material. Further information on radiological hazards can be found in Appendix A.

Figure 1.2 shows the most important processes of radionuclide transfer in an inhabited area, the different hazards posed and the exposure pathways for humans. The exposure pathways which contribute most significantly to the exposure of humans in an inhabited area are external exposure from contamination on surfaces and inhalation of resuspended contaminated material. In certain cases, other exposure pathways, for example inadvertent ingestion of contaminated material, may warrant investigation. This pathway has been considered for people working with contaminated waste, but it is not considered in detail in the Handbook. The ingestion of contaminated food, although not discussed in this Handbook is also an important exposure pathway. The Handbook for Food Production Systems should be consulted for further information on this pathway and how radionuclide transfer may be reduced.

The radionuclides considered in the Handbook have been grouped according to both their radioactive half-lives and whether their hazard arises mainly from emission of gamma, beta or alpha radiation. Half-lives and types of radiation emitted by radionuclides included in the Handbook are given in Table 1.1.

Figure 1.2 Primary exposure pathways of relevance to the recovery phase of a radiological incident



In general it is expected that a mix of radionuclides would be released into the environment following a radiological incident. As shown in Table 1.1 often a radionuclide emits predominantly a single type of radiation and, as a result, one exposure pathway normally dominates for a single radionuclide. However, for some radionuclides and depending on the circumstances of the incident, people's habits and whether they are members of the public or recovery workers, there may be cases where other exposure pathways should be considered.

Table 1.1 Predominant emissions and half-life for each radionuclide considered in the Inhabited Areas Handbook

Radionuclide		Alpha (MeV)	Beta (MeV)	Gamma (KeV)	Dominant radiation type	Radioactive half-life
Symbol	Name					
^{60}Co	Cobalt-60	–	1.48 (0.1%) 0.31 (99%+)	1173 (100%) 1332 (100%)	Gamma	5.27 y
^{75}Se	Selenium-75	–	–	265 (60%) 136 (57%)	Gamma	119.8 d
^{90}Sr + ^{90}Y	Strontium-90 + Yttrium-90	–	0.546 2.27	–	Beta	29.12 y
^{95}Zr	Zirconium-95	–	0.89 (2%) 0.396	724 (49%) 756 (49%)	Gamma	63.98 d
^{99}Mo + ^{99m}Tc	Molybdenum-99 + Technetium-99m	–	1.23	740 (12%) 81 (7%)	Gamma	66 h
^{103}Ru	Ruthenium-103	–	0.70 (3%) 0.21	497 (88%) 610 (6%)	Gamma	39.28 d
^{106}Ru + ^{106}Rh	Ruthenium-106 + Rhodium-106	–	3.54	512 (21 %) 622 (11%)	Gamma	368.2 d
^{132}Te	Tellurium-132	–	0.22	53 (17%) 230 (90%)	Gamma	78.2d
^{131}I	Iodine-131	–	0.606	364 (82%) 637 (6.8%)	Gamma	8.04 d
^{134}Cs	Caesium-134	–	0.662	796 (99%) 605 (98%)	Gamma	2.062 y
^{136}Cs	Caesium-136	–	0.341 0.657	819 (100 %) 1048 (80%)	Gamma	13.1 d
^{137}Cs + ^{137m}Ba	Caesium-137 + Barium-137m		1.176 (7%) 0.514	662 (85%)	Gamma	30 y
^{140}Ba	Barium-140	–	1.02	438 (5%) 537 (34%)	Gamma	12.74 d
^{144}Ce	Cerium-144	–	0.318 0.238	133.5 (100%)	Gamma	284.3 d
^{169}Yb	Ytterbium-169	–	–	63(45%) 198 (35%)	Gamma	32.01 d
^{192}Ir	Iridium-192	–	0.67	317 (81%) 468 (49%)	Gamma	74.02 d
^{226}Ra	Radium-226	4.78 (95%) 4.60 (6%)	3.3	186 (4%) 260 (0.007%)	Alpha	1.6 10^3 y
^{235}U	Uranium-235	4.40 (57%) 4.37 (18%)	0.3	185 (54%) 143 (11%)	Alpha/ Gamma*	7.04 10^8 y
^{238}Pu	Plutonium-238	5.50 (72%) 5.46 (28%)	–	99 (0.008%) 150 (0.001%)	Alpha	87.74 y
^{239}Pu	Plutonium-239	5.16 (88%) 5.11 (11%)	–	52 (0.02%) 129 (0.005%)	Alpha	2.4 10^4 y
^{241}Am	Americium-241	5.49 (85%) 5.44 (13%)	–	60 (36%) 101 (0.04%)	Alpha/ Gamma*	432.2 y

Notes:

*: For these radionuclides inhalation doses from resuspended material are mainly due to the alpha radiation emitted, but if the contamination is fixed to surfaces and not available for resuspension, only external exposure to gamma radiation contributes to the dose

1.8 Inhabited areas

What is an “inhabited area”?

Inhabited areas are places where people spend their time. They can be divided into a number of sub-areas such as residential, industrial and recreational. These sub-areas contain a variety of surfaces such as buildings, roads, woodlands and parks.

The sub-areas and surfaces found in inhabited areas are described in Table 1.2 and Table 1.3 respectively.

Figure 1.3 shows the types of surface which can be found in each sub-area.

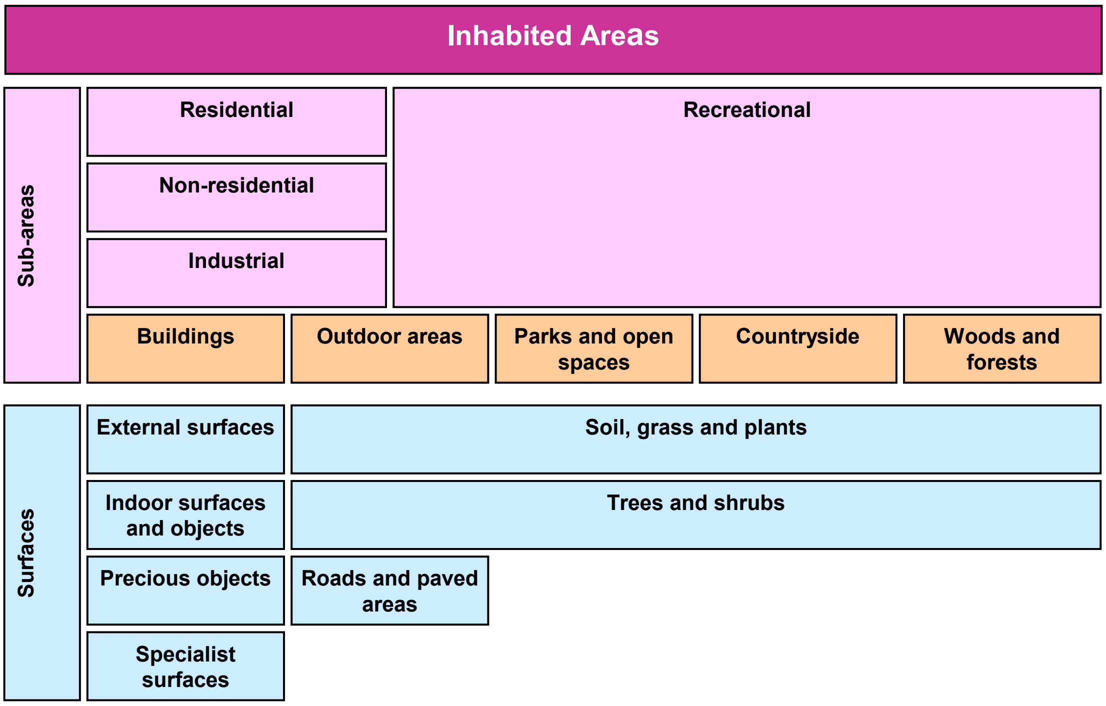
Table 1.2 Types of sub-areas in inhabited areas

Sub-area	Description
Residential	Areas used for residential purposes (e.g. houses, small settlements, housing estates, block of flats).
Non-residential	Areas accessed by the public for services and employment (e.g. commercial districts, shopping centres, supermarkets, town and city centres).
Industrial	Non-residential areas where production and/or commercial activities are undertaken (e.g. industrial estates, factories).
Recreational	Outdoor areas accessed by the public for recreation.
The sub-areas may comprise:	
Buildings	Buildings used for residential, public, commercial and industrial purposes. Also includes buildings key to the provision of infrastructure in an area, such as railway stations and water treatment plants.
Outdoor areas	Areas with private access from residential dwellings (e.g. playing areas, driveways, patios, gardens) and areas with public access (e.g. roads, pavements, car parks, gardens, playing fields, playgrounds).
Parks and open spaces	All gardens, parks, children's play areas and sports fields with public access. Size of these areas is typically greater than 300 m^2.
Woods and forests	Managed and unmanaged deciduous and coniferous woods and forests used for recreation purposes by the public.
Countryside	Managed and unmanaged areas used for recreational purposes by the public (e.g. footpaths, national parks, moorland).

Table 1.3 Surfaces in inhabited area

Surface	Description of surface
Buildings - external surfaces	External hard surfaces (e.g. walls, roofs, windows and doors of all buildings)
Buildings - indoor surfaces and objects	Indoor building surfaces (e.g. walls, floors, ceilings, soft furnishings and furniture)
Buildings - precious objects	Objects for which disposal is unacceptable and for which normal decontamination methods may cause unacceptable damage (e.g. museum pieces, artwork, original documents and personal items)
Buildings - specialised surfaces	Metal, plastic and coated surfaces found in industrial and commercial buildings. Also includes ventilation systems.
Roads and paved areas	All roads, pavements, large paved or asphalt areas (e.g. playgrounds, yards and car parks)
Soil, grass and plants	Includes lawns, flowerbeds and vegetable plots associated with the gardens of residential dwellings, landscaping around commercial and public buildings, allotments, parks, playing fields and other managed green areas.
Trees and shrubs	Includes all woody plants (e.g. trees, shrubs and bushes) associated with the gardens of residential dwellings, landscaping around commercial/public buildings, orchards, allotments, parks, playing fields and other managed green areas.

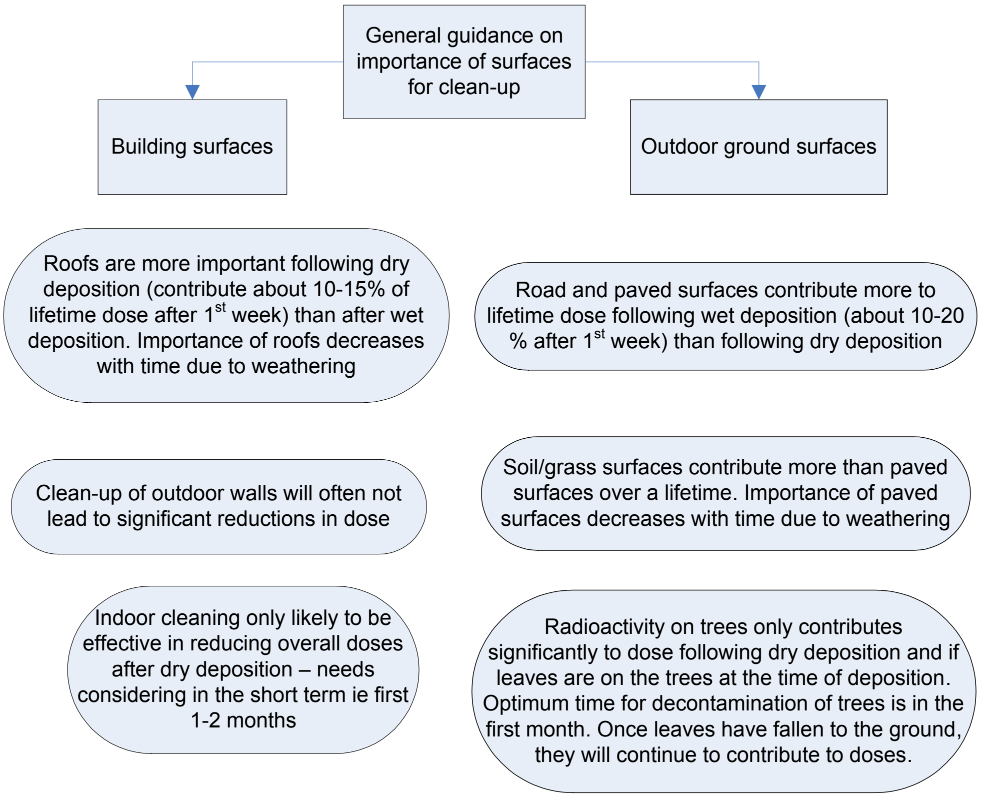
Figure 1.3 Link between types of inhabited area and surfaces



1.8.1 Importance of different surfaces in influencing radiation exposure

The relative importance of the various surfaces in contributing to doses from external exposure depends on a number of specific factors, such as the radionuclides released and their physical/chemical forms, the type of area, the amount of precipitation at the time of deposition, weathering and redistribution of the radionuclides onto other surfaces. If the source of contamination is outdoors, contamination on outdoor surfaces always plays a major role. If the deposition occurs during rainfall (wet deposition) doses from deposition on indoor surfaces are likely to be much lower than doses from deposition on outdoor surfaces. If deposition occurred at a time when there is no rain (dry deposition) doses from indoor surfaces assume higher importance. Furthermore, deposition of radioactive material under dry or wet weather conditions results in different distributions of the contamination on different surfaces (see Appendix A for further information). For example, wet deposition onto house walls is minimal, owing to their vertical orientation. In addition, surfaces with the highest radioactive contamination may not provide the highest contribution to the exposure of the inhabitants of a contaminated area, as these people may spend more time close to less contaminated surfaces. In estimating doses to the public, it is therefore necessary to carefully evaluate exposure contributions from contamination on each surface. Figure 1.4 gives an indication of the likely importance of surfaces found in inhabited areas in contributing to external gamma doses following deposition of a long-lived radionuclide, e.g. ^{137}Cs, in a typical inhabited area following a release outside the inhabited area, such as a reactor accident (Brown et al, 1996). The relative importance of time spent outdoors and indoors on doses is taken into account by assuming that people spend 90% of their time indoors.

Figure 1.4 Likely importance of surfaces in contributing to external dose



Roofs are more important following dry deposition (contribute about 10-15% of lifetime dose after 1st week) than after wet deposition. Importance of roofs decreases with time due to weathering

Clean-up of outdoor walls will often not lead to significant reductions in dose

Indoor cleaning only likely to be effective in reducing overall doses after dry deposition – needs considering in the short term ie first 1-2 months

Road and paved surfaces contribute more to lifetime dose following wet deposition (about 10-20 % after 1st week) than following dry deposition

Soil/grass surfaces contribute more than paved surfaces over a lifetime. Importance of paved surfaces decreases with time due to weathering

Radioactivity on trees only contributes significantly to dose following dry deposition and if leaves are on the trees at the time of deposition. Optimum time for decontamination of trees is in the first month. Once leaves have fallen to the ground, they will continue to contribute to doses.

The information in Figure 1.4 is also likely to be applicable to long-lived beta emitting radionuclides such as ^{90}Sr. This information is not necessarily appropriate for releases occurring within an inhabited area (e.g. a dirty bomb), as the distribution of contamination between surfaces may be very different.

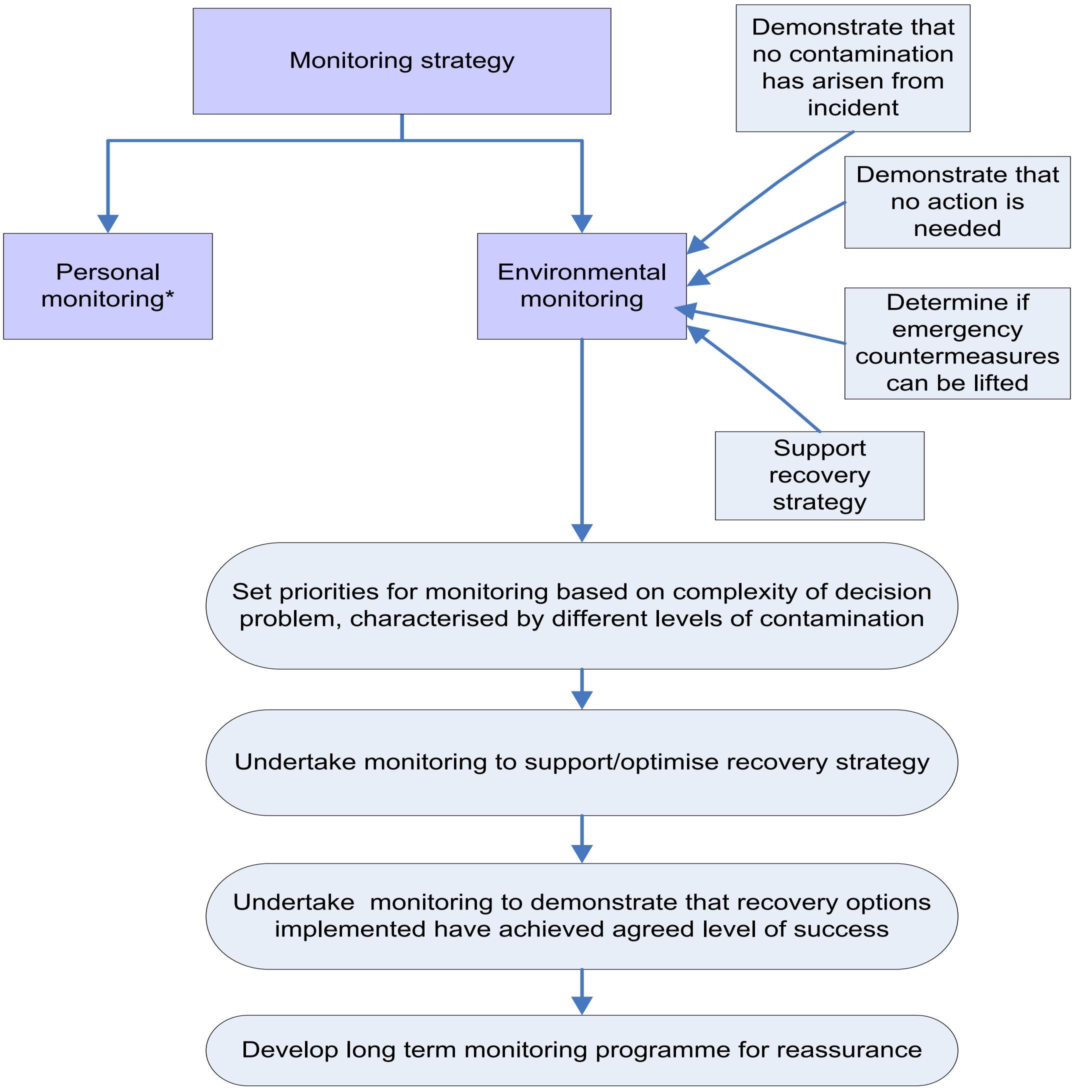
1.9 Determining the nature and extent of the incident and characterising the contamination

It is unlikely that, at the start of the recovery phase, decision makers have a detailed picture of the full distribution of the contamination deposited on the ground. Since it is important to base recovery decisions on as clear a picture as possible of the contamination pattern and the likely doses to people, an appropriate strategy for detailed monitoring for both people and the environment needs to be implemented (Morrey et al, 2004). This strategy needs to identify priorities for monitoring as well as the types and scale of monitoring required and should also consider the needs for monitoring in different situations. Key requirements for monitoring are:

- to demonstrate that no contamination has arisen from the incident
- to demonstrate that no action is needed
- to determine if emergency countermeasures can be lifted
- to determine people's exposures (personal monitoring)
- to support a recovery strategy, i.e. to determine where clean-up is needed and demonstrate that options implemented have achieved an agreed level of success
- to provide long-term reassurance.

Figure 1.5 provides an overview of the role of environmental monitoring in the recovery phase. The development of a detailed monitoring strategy is not discussed further.

Figure 1.5 General roles of environmental monitoring for inhabited areas



* Personal monitoring is not considered further in this Handbook.

1.10 General radiological protection principles and criteria

The International Commission on Radiological Protection (ICRP) is the primary international body for recommending radiological protection standards. After a consultation process lasting several years, in 2007 the ICRP published new recommendations for a system of radiological protection in Publication 103 (ICRP 2007) replacing the 1990 Recommendations (ICRP 1991a). However, it will take several years before Publication 103 becomes incorporated into national legislation so this section primarily relates to the 1990 Recommendations.

1.10.1 Practices and Intervention

The 1990 Recommendations distinguishes two situations for which the system of radiological protection applies, ‘practices’ and ‘interventions’.

1.10.1.1 Practices

Practices are situations that are under control and that lead to increases in the exposure of individuals such as during the operation of nuclear power stations. Emphasis is on the control of the source of exposure and this can generally be planned for before commencing the practice. ICRP's principles of protection for practices (endorsed by HPA for use in the UK) are:

- no practice involving exposures to radiation should be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes. This is known as the justification of a practice
- in relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be received should all be kept as low as reasonably achievable, economic and social factors being taken into account. This procedure should be constrained by restrictions on the doses to individuals (dose constraints), or the risks to individuals in the case of potential exposures (risk constraints), so as to limit the inequity likely to result from the inherent economic and social judgements. This is known as the optimisation of protection
- the exposure of individuals resulting from the combination of all the relevant practices should be subject to dose limits, or to some control of risk in the case of potential exposures. These are aimed at ensuring that no individual is exposed to radiation risks that are judged to be unacceptable from these practices in any normal circumstances.

In simpler terms, these principles may be phrased as follows: radiation can cause harm and therefore any intended use should be worthwhile (justification) and, this being the case, all reasonable steps should be taken to reduce exposures from a single source below predefined constraints (optimisation). Doses and risks to an individual from all relevant sources of radiation should be kept within pre-defined limits (dose and risk limitation).

1.10.1.2 Intervention

Interventions are situations where the sources, pathways and exposed individuals are already in place when a decision on control has to be taken such as during actions taken to reduce existing radon exposures. In such situations, protection can only be achieved by removing or modifying existing sources or pathways, or reducing the numbers of people exposed. ICRP (ICRP, 1991b) have recommended the following general principles governing the system of radiological protection for intervention:

- countermeasures should be introduced if they are expected to achieve more good than harm. This is known as the justification of intervention
- the quantitative criteria used for the introduction and withdrawal of countermeasures should be such that the protection of the public is optimised. This is known as the optimisation of intervention
- serious deterministic health effects should be avoided by introducing countermeasures to keep doses to individuals to levels below the thresholds for these effects.

In most cases, intervention cannot be applied to the source of the exposure and has to be applied in the environment and, particularly in the case of accidents, to an individual's freedom of action. Thus a programme of intervention will always have some disadvantages but should always be justified in the sense that it does more good than harm. It follows that the use of dose limits, or constraints, specified for practices as the basis for deciding on a level at which intervention is invoked might involve measures that would be out of proportion to the benefit obtained and, therefore, would conflict with the principle of justification. Thus, dose limits for practices (and, by inference, dose constraints) do not determine whether or not intervention should be undertaken. There will, of course, be some level of dose approaching that which would cause serious deterministic effects, where some form of intervention will almost always be required.

Clearly, intervention aims to avoid or avert exposure to radiation. Hence one important quantity in taking decisions on intervention is the level of dose averted by taking the remedial action (avertable dose). However, for actions undertaken during the recovery phase, it should be recognised that an equally important aim is to promote an early return to ‘normal living’. Thus decision makers should consider, not only the expected consequences of implementing the strategy (e.g. the avertable dose, the costs, resources required, likely duration, level of disruption etc), but also how implementing this strategy will contribute to the re-establishment of ‘normality’, including, specifically, the criteria on which protective measures will be considered successful (and so can be terminated).

For situations requiring intervention, the concept of a level of dose, or directly measurable quantity, above which action should be taken, can be useful. Such criteria are termed action levels (ALs). Generic ALs may be developed before an accident (e.g. those adopted for food) or in the event of an accident, taking account of the specific circumstances.

1.10.1.3 Which system of protection for the recovery phase?

The systems of protection for both practices and intervention are relevant for the recovery phase. The system of protection for intervention would be used in the process of deciding on the form and scale of the actions taken to recover from contamination of the environment from accidental releases of radioactivity. However, the workers undertaking such actions would be potentially exposed to an additional source of radiation so their exposure would be controlled under the system of protection for practices. Similarly, the handling and disposal of any wastes produced during the recovery actions away from the contaminated area would be controlled under the system of protection for practices.

1.10.2 Key features of the new 2007 Recommendations relating to the recovery phase

The fundamental principles of radiological protection – justification, optimisation and application of dose limits, remain the same and the dose limits are unchanged from the 1990 Recommendations. ICRP has, however, made some changes to the structure of the system of protection in order to improve clarity.

In the 2007 Recommendations ICRP has divided exposure situations into three types, which encompass the entire range of plausible exposure situations: planned exposure situations which involve the deliberate legitimate introduction and operation of sources; existing exposure situations which are situations where exposures already exist when a decision on protection has to be taken; and emergency exposure situations which require urgent action to avoid or reduce undesirable exposures. Within the framework described in the 2007 Recommendations, emergency response and its aftermath will evolve through two types of exposure situations: emergency exposure situations and existing exposure situations. ICRP uses the categorisation of exposure situations to highlight differences in the way the situations are managed: there may not be clear cut boundaries between the physical attributes of the exposures themselves. The management of the emergency exposure situations is characterised by recognition that the situation is 'abnormal' and that actions are required to protect people and to help restore the situation to 'normal'. Emergency response management is therefore concerned with initiating and managing change on a short timescale. Existing exposure situations resulting from emergencies, on the other hand, are situations where the on-going radiation risks are tolerable, even with only limited, or no, further protective actions, although the environmental contamination and potential exposures are recognised as being higher than would be accepted for planned situations. In short it is recognised that the impact of significant further environmental remediation on the people affected and on society more generally would outweigh any expected benefits. Thus a new normality can be established, which requires sustaining. The management of existing exposure situations is therefore characterised by enabling and promoting normal living in an area recognised as having higher potential exposures than other areas. This may involve continuing less disruptive protective actions, such as regular environmental monitoring, but the focus of management would be on the maintenance of normal living, not a change to normal living. The Inhabited Areas Handbook is likely to be applicable to both emergency exposure situations and existing exposure situations, although the focus is more on the latter.

1.11 Radiological protection criteria for inhabited areas

Any protection criterion aimed at reducing the risks of stochastic health effects, i.e. cancer, must take into account all the wider consequences of the proposed protective measure, such as cost and disruption, and balance these aspects against the expected benefits provided by the measures implemented, including public reassurance. This balance needs to take account of the specific circumstances of the event is likely to vary between different types of incidents and contamination. There are currently no international or national regulations outlining clean-up criteria that could be used directly following an incident involving radiation. Some clean-up techniques are considerably more resource-intensive and disruptive than others. Following an incident therefore, assessments should be undertaken of all the likely consequences of a range of clean-up strategies. These consequences should include cost, timescales, public acceptability and the availability of the necessary resources, as well as the expected reduction in risks of health effects. Clearly, collection in advance of information relevant to these assessments, such as the likely effectiveness and resource requirements of different clean-up options, and prior identification and preparation of appropriate equipment and contractors, would facilitate the timely completion of such assessments in the event of an incident. Potential strategies that involve high levels of cost and disruption should only be undertaken if the expected reduction in risk of stochastic health effects is also high, thereby maintaining a balance between the expected harms and benefits of the strategy. Current international guidance (ICRP, 2007) recommends that every effort be made to avoid individuals receiving lifetime doses greater than 1 Sv and therefore all types of protective measures should be considered for this eventuality.

1.12 Estimating doses in inhabited areas

As mentioned in Section 1.8.1, the dose to an individual from exposure to a given amount of radioactive material deposited following a radiological incident can vary widely, depending on the radionuclides involved, the spread of the contamination between different surfaces and the time spent by the individual at locations with different levels of contamination. The dose an individual living in a contaminated environment receives is the sum of the doses arising from the differing levels of contamination on different surfaces at a variety of locations. The total dose received by an individual is therefore determined by the time spent in each location and the dose rate at that location, which varies with time as the activity of the radionuclides decay.

In general members of the public should be equally protected in all areas where they spend time or, in other words, the dose rates in areas where they work and spend their spare time should be no higher than those where they live. This means that the doses at which the various categories of options should be considered should be calculated assuming that people spend all their time at that location, taking account of the time spent indoors at the location if appropriate.

If there are very good reasons why people may need to be exposed to higher dose rates, e.g. those maintaining critical facilities and infrastructure, the doses to these people must be controlled and all other people must be excluded from the area. In this case, it would be reasonable to take into account the amount of time spent in the specific environment being considered.

Ideally, the estimation of doses in an area should take account of the characteristics of the area (e.g. the types of building in the area, the level of urbanisation, the surface area of gardens, parks and other amenities) and the temporal variation of the contamination as a function of time. Appendix B provides some guidance on basic methods to estimate doses in inhabited areas from given levels of contamination.

1.13 References

ICRP (1991a). 1990 Recommendations of the ICRP. ICRP Publication 60. Annals of ICRP, 21 (1-3)

ICRP (1991b). Principles for intervention for protection of the public in a radiological emergency. ICRP Publication 63. Annals of ICRP, 22 (4)

ICRP (2007) Recommendations of the ICRP. ICRP Publication 103. Annals of ICRP 37 (2-4)

Morrey M, Nisbet A, Thome D, Savkin M, Hoe S and Brynildsen L (2004). Response in the late phase to a radiological emergency. *Radiation Protection Dosimetry,* 109, 89-96.

CONTENTS OF SECTION 2

2 MANAGEMENT OPTIONS

The term management option is defined as an action intended to reduce or avert the exposure of people to radioactive contamination. Management options were previously referred to as countermeasures. This Handbook has identified 59 potential management options for use in contaminated inhabited areas; 11 cover the pre-release and emergency phase of an incident; 48 are for the recovery phase. The Handbook focuses mainly on the 48 options for the recovery phase. These can be divided into two main groups: options that shield people from the contamination (shielding options) and those that remove contamination (removal options also called decontamination or clean-up options). The implementation of management options is generally the responsibility of the authorities, however self-help options, which may be implemented by the affected population can also be useful (see Section 2.3). It is also important to note that the option not to carry out any recovery can be a valid alternative; more information on this topic is provided in Section 2.5.

Figures 2.1 - 2.4 give the options considered in the Handbook for each of the surface types described in Figure 1.2. In these figures, shielding options are shaded green and removal options are shaded in yellow. The number in brackets refers to the relevant datasheet (Section 3). Only options for the recovery phase are considered in these figures.

Figure 2.1 Management options for buildings

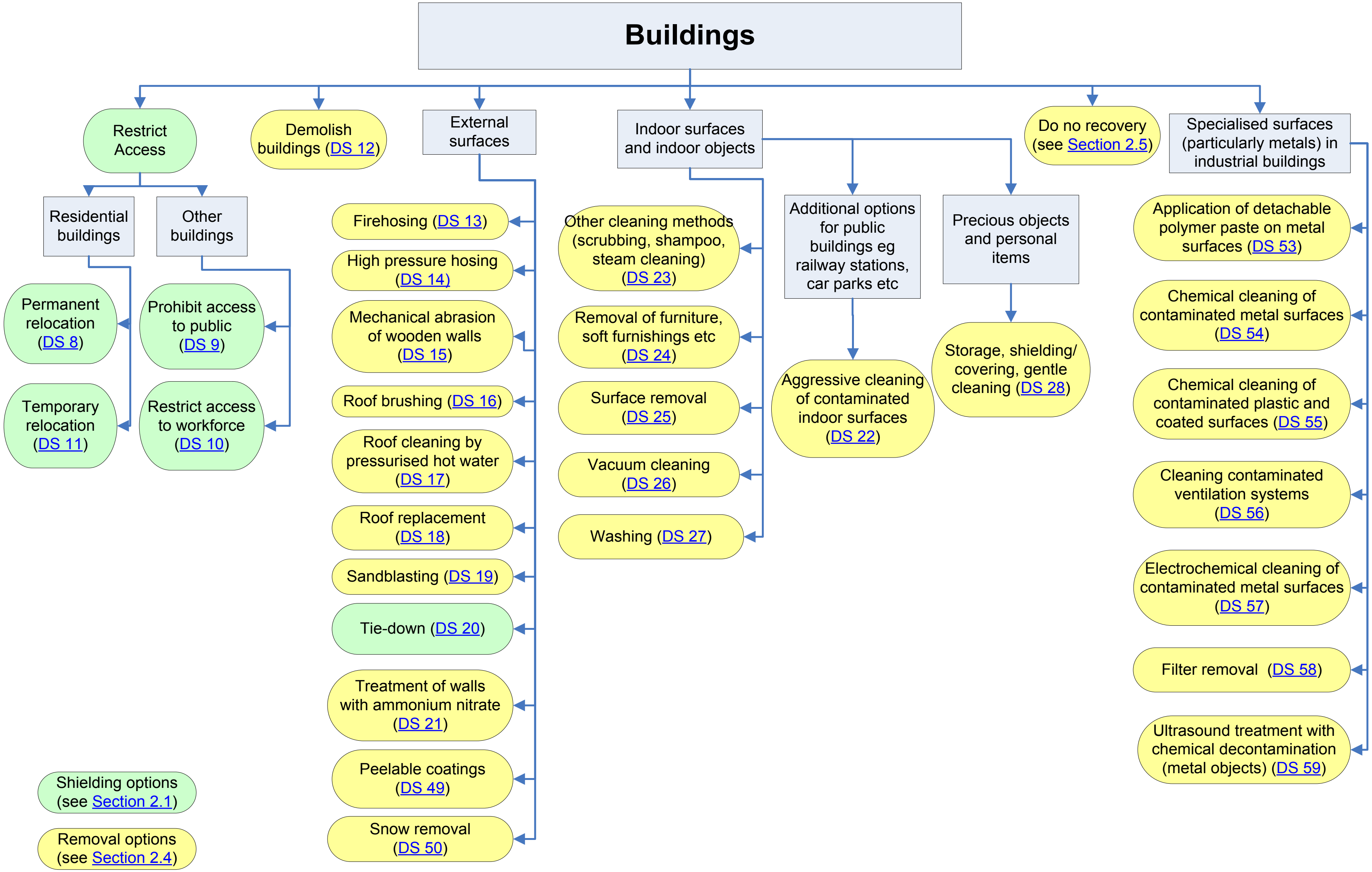


Figure 2.2 Management options for roads and paved areas

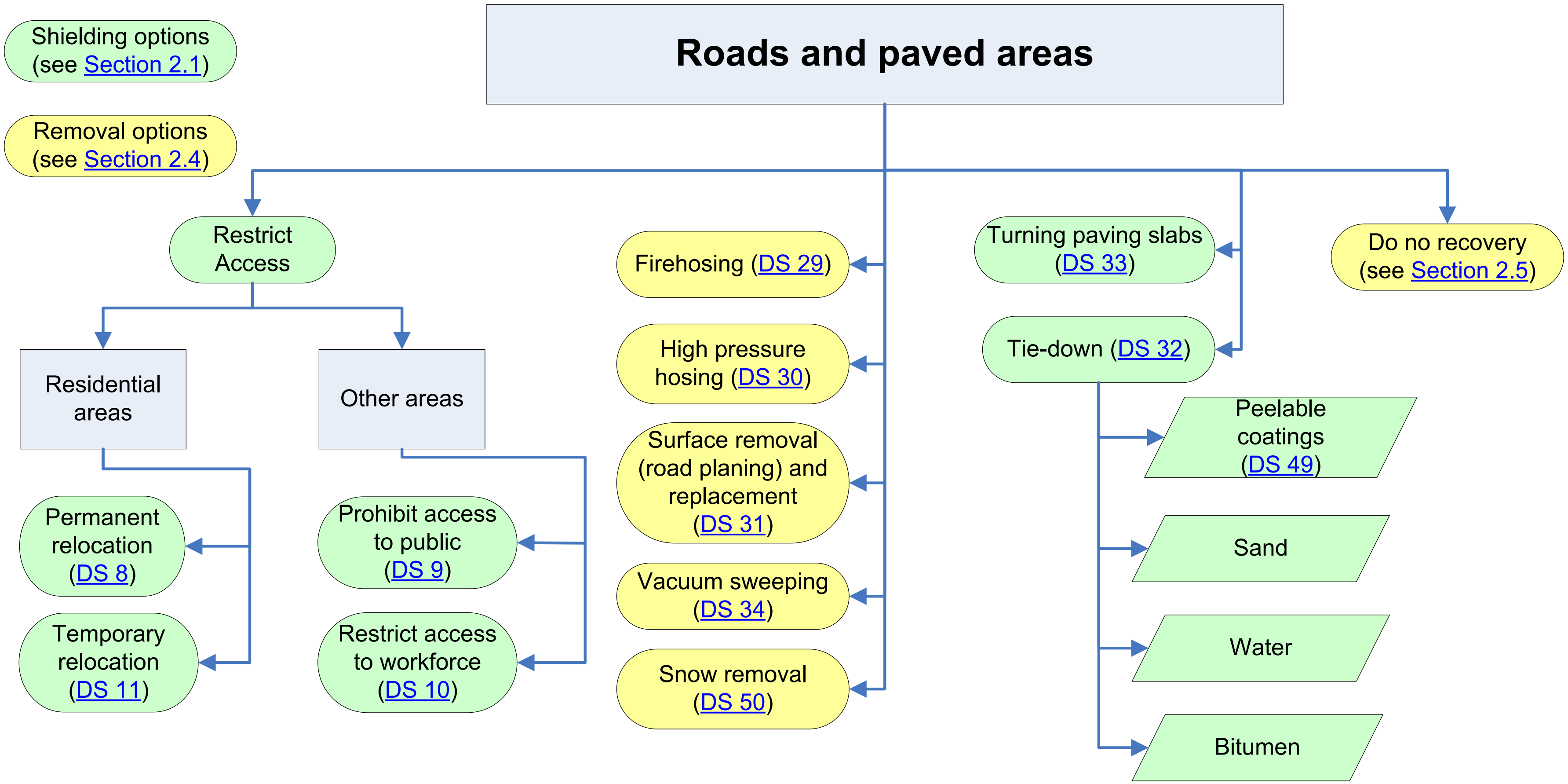


Figure 2.3 Management options for soil, grass and plants

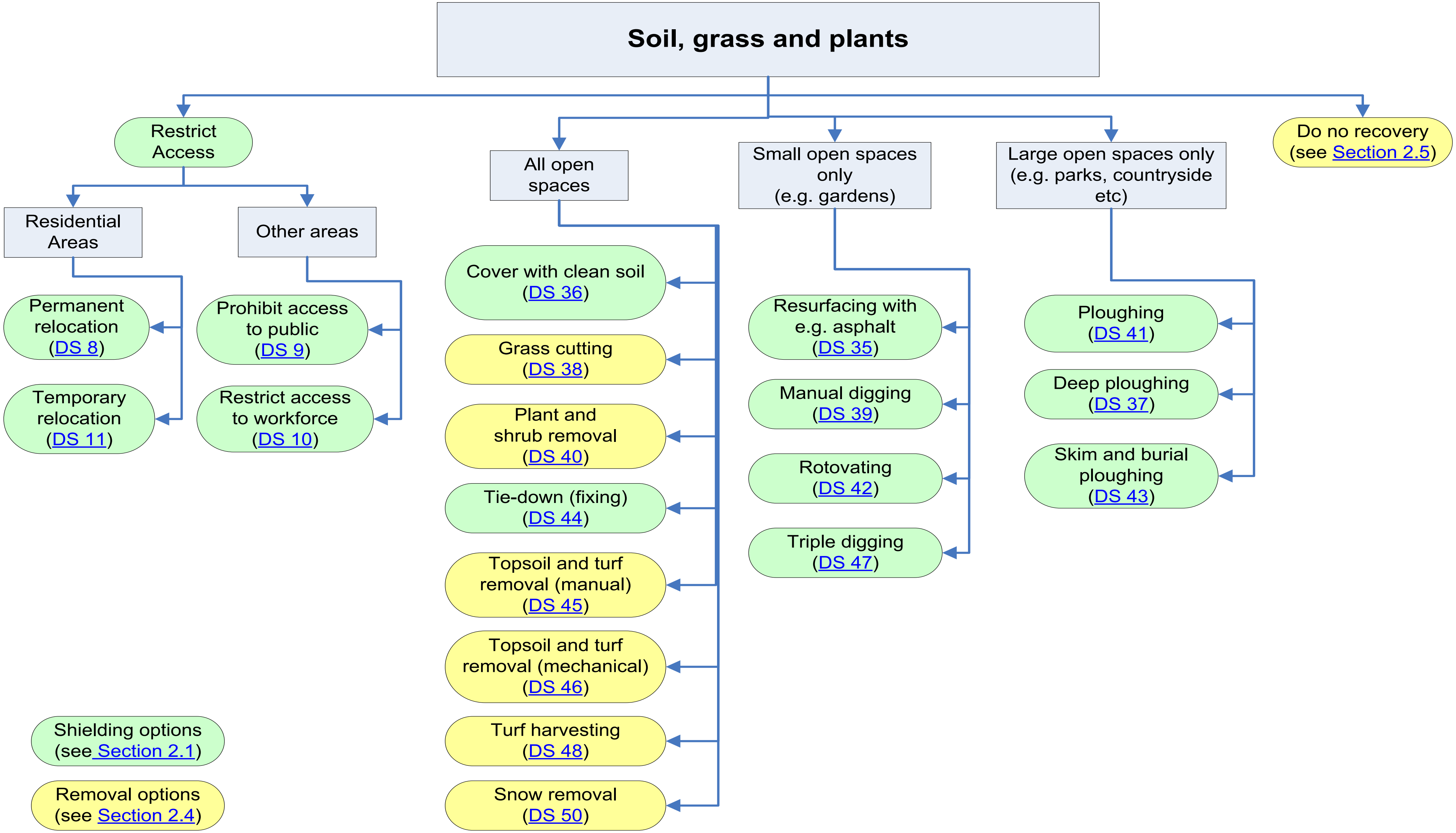
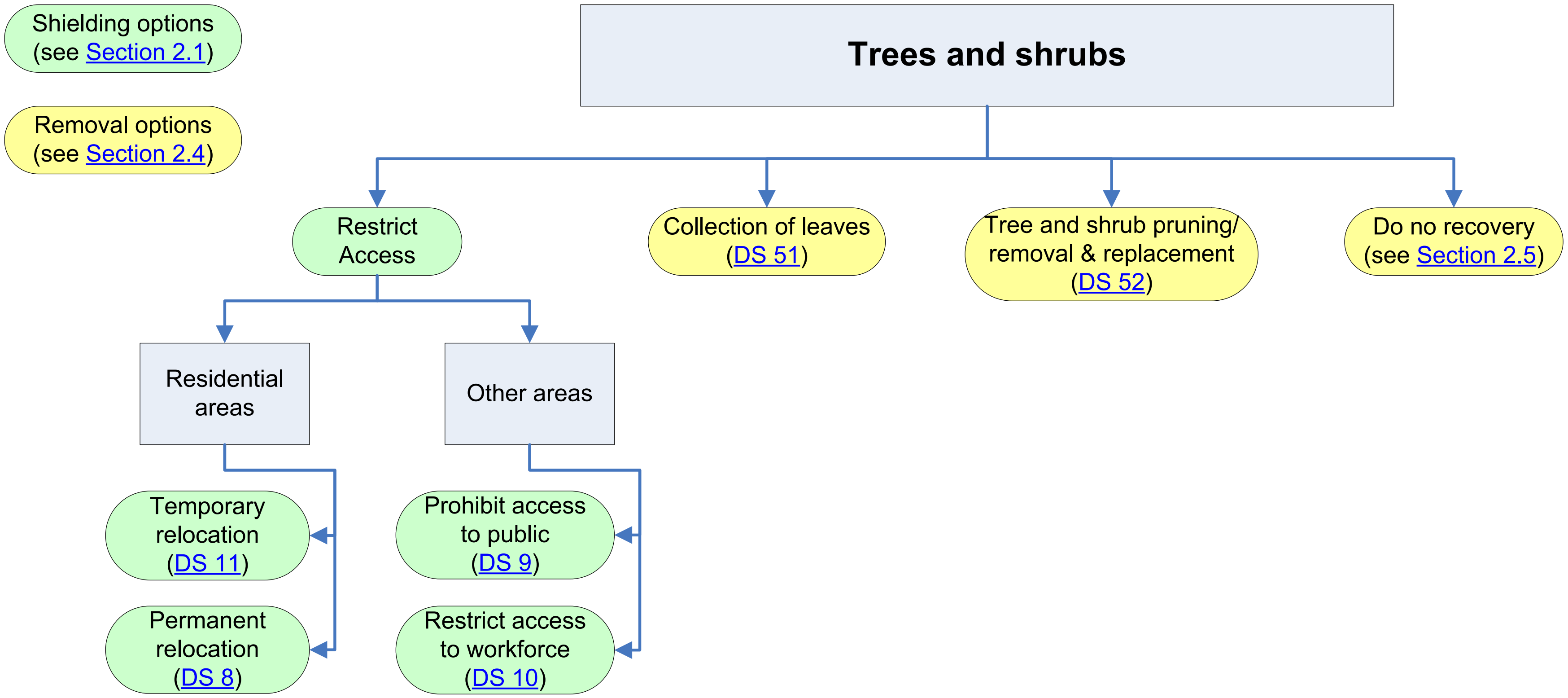


Figure 2.4 Management options for trees and shrubs



2.1 Shielding options

Shielding options can be used to reduce both external exposure and the intake of contaminated material, but are usually particularly effective in providing protection against either one of these exposure pathways. The use of shielding materials is potentially a very effective option for radionuclides emitting alpha or beta radiation, particularly if they are relatively short-lived. Some more permanent shielding options, such as burial of contaminated material or the permanent relocation of people from a contaminated area are also effective for long-lived radionuclides and gamma emitting radionuclides. Appendix A3 provides detailed information on the use of shielding materials for reducing doses.

2.1.1 Types of shielding

There are three main types of shielding options:

- burial and covering of objects
- restricting access of people or relocating people from the area, including storing of objects.
- fixing of contamination

If the primary aim is to reduce external exposure, shielding materials can be placed between the contamination and people (burial and covering of objects). Examples include the use of clean topsoil in gardens and other open areas and the turning of paving slabs. In general, these types of options are more effective in reducing external dose rates from radionuclides emitting beta radiation than for those emitting gamma radiation. Inhalation doses from resuspended material are also reduced while the shielding material is in place.

Reduction in external exposure can also be obtained by relocating people from the contaminated area or restricting access to contaminated areas or objects. In this case, air acts as the shielding medium. Such options are 100% effective against all radioactive contaminants while they are in place, as people do not receive any dose from the area from which access is restricted.

If the primary aim is to protect against the intake of contaminated material into the body, shielding material is used to fix the contamination to the surface and restrict its mobility. Fixing options also have the benefit of providing shielding from external exposure but the effectiveness of the shielding is likely to be secondary to the dose reduction achieved for internal exposure. Furthermore, removal of fixing materials can also remove some of the underlying contamination held on the surface as dust. The main advantages and disadvantages of shielding options are outlined in Table 2.1.

Table 2.1 Advantages and disadvantages of shielding options

Advantages
No waste is generated directly.
They are unlikely to have a lasting negative effect on the environment. Some options may make the environment look cleaner (e.g. resurfacing roads).
People can remain in the area during implementation, except for relocation.
They are easier and quicker to implement than removal options, except relocation.
Fixing contamination to a surface is very effective at protecting against alpha emitters and may also provide good shielding for beta emitters and limited shielding for gamma emitters, depending on the material used and its thickness. Fixing options also prevent resuspension while the fixing material is in place.
Disadvantages
Contamination is not removed from the affected area. Therefore it may be necessary to deal with a public perception that the contamination, albeit shielded from people, still exists.
If burial options such as ploughing are implemented, it is important to be sure that they are effective in reducing doses such that there will be no need to remove contamination at a later date. Once contamination is buried, its subsequent removal will result in more radioactive waste being produced, albeit with lower levels of contamination.
Restricting access to areas, buildings and objects limits a return to normal living.
Permanent shielding by fixing contamination to the surface may cause problems with future maintenance of the surface, which could give rise to doses to the workforce and waste disposal issues.
The integrity of the fixing material may diminish with time, reducing its effectiveness.
If shielding is provided by temporarily fixing contamination to a surface, the disposal of the materials used may be required, as they can become contaminated.

2.2 Removal options

Removal options involve the decontamination or clean-up of contaminated surfaces and objects. The main advantages and disadvantages of removal options are listed in Table 2.2. One of the main disadvantages is that contaminated waste material is produced, often in large quantities. There may also be major constraints on the use of removal options on historic buildings or buildings that are in poor condition where unacceptable damage to the fabric of the buildings may occur. For example, high pressure hosing and sandblasting may cause significant damage to old or poorly maintained brick or stone buildings.

Similarly, it may not be practicable to carry out decontamination techniques that directly affect the surface of objects due to the damage that such techniques may cause. For example, this may be particularly true for objects found in heritage buildings and museums. These objects may, however, withstand gentle washing or vacuuming without causing damage to their surfaces. It is likely that disposal of such objects will be unacceptable because of their monetary or heritage value, and therefore if all decontamination techniques prove unacceptable or impracticable, storage or shielding of the objects could be considered. It should be recognised that these objects would mostly contribute relatively little to the dose and their cleaning would therefore often have the primary purpose of public reassurance.

Table 2.2 Advantages and disadvantages of removal options

Advantages
They remove contamination from the affected area.
Effectiveness in reducing external doses and inhalation doses arising from resuspended material. However, it is likely that the techniques will have to be used on several surfaces to provide significant dose reductions.
Physical removal works equally well for all types of contaminant, although the thickness of surface layers to be removed may be dependent on the contaminant(s). Use of chemical reagents may or may not be contaminant-specific.
Disadvantages
All removal options create waste.
They create disruption.
Unacceptable damage may be done to building surfaces and objects, particularly if old or in poor condition.
Negative effect on the environment.
Some contamination may remain in the affected area unless drastic, environmentally damaging removal options are undertaken.
For some options it may be necessary to move people out of the area while the contamination is removed. This would almost certainly imply temporary closure of schools, hospitals and businesses, for example.

2.3 Self-help management options

Self-help management options are simple measures that may be carried out by people living in the affected areas rather than skilled workers and which, in general, require no specific expertise or experience to be implemented. Information on the suitability of the management options considered in the Handbook for self-help is given in each datasheet under the heading ‘Required skills’ (Section 3). The advantages and disadvantages of management options being implemented by affected inhabitants rather than other workers are given in Table 2.3. After the Chernobyl accident, self-help schemes introduced in the highly contaminated areas of the former Soviet Union have generally been perceived by the affected populations as very positive (Beresford et al, 2001). Some technical factors require specific consideration prior to initiation of self-help management options (see Table 2.4).

Table 2.3 Advantages and disadvantages of implementing self-help options

Advantages
They involve people affected in the effort to improve their own situation. This can help people understand the relative importance of different exposure routes and lead to a better understanding of how exposures can be reduced.
Affected inhabitants get a better feeling that they are in control of the situation and the knowledge obtained through direct involvement can prevent unnecessary anxiety.
Affected inhabitants know exactly what has been done to improve the situation and how well it has been done.
They are comparatively cost-effective in terms of costs of labour.
They have the benefit of introducing an extra labour resource in cases where large areas need to be treated over a relatively short time period (e.g. grass cutting and collection).
They comply with the important ethical values of autonomy, liberty and dignity.

Table 2.3 Advantages and disadvantages of implementing self-help options

Disadvantages
People participating in recovery operations would be subject to the dose limitation system for members of the public.
People participating in recovery operations would require protection.
They need to be carried out on a voluntary basis.
Carefully worded and detailed communication with the people participating would be required. This could take considerable time to implement.
Techniques may not be implemented effectively.

Table 2.4 Technical factors to consider for self-help management options

Factor	Comment
Safety precautions	These are listed in datasheets (see Section 3). As self-help management options introduce a higher degree of autonomy, it needs to be stressed that no management option should be implemented before adequate safety instructions and equipment are in place.
Specific protection of unskilled people	Methods involving undue risk (e.g. work at elevated height or use of chainsaws) have been excluded by default. People may also not be physically fit for the work.
Safety in connection with waste handling	People may receive relatively high doses near piles or vessels containing concentrated contaminated material generated by self-help measures (e.g. from grass cutting and collection). Inhabitants would need careful instruction to minimise time spent in such locations over the period before the waste is collected.
Information on objective	The objective of a management option should be clear. This may partially be done through leaflets, but for some management options (e.g. digging), initial supervision would be recommended, as adverse effects of incorrect implementation can be irreversible.
Availability of equipment	Most of the primary equipment required would need to be available in the majority of households. Some additional equipment may need to be secured and this will need to be made available on the required timescale.
Monitoring in optimisation	Monitoring by skilled workers to determine the contaminant distribution should precede techniques involving soil digging or removal of soil layers.

2.4 Implementing management options with people in-situ

It may be difficult to undertake management options in an area in which people are still living and working, particularly in residential areas. It is recognised, however, that it might not be possible to relocate people temporarily during this time, particularly if the number of people involved is large.

If decision makers wish to avoid either moving people temporarily out of an area or restricting access to it during the implementation of management options, the following factors need to be considered:

- awareness that many people may self-evacuate anyway, in which case the area will need to be made secure
- provision of a comprehensive information service. With good advice and information, many people will be happy to stay in their homes.
- management options should be carried out as quickly as possible. If people are left in a residential area, the length of time they can be asked to stay indoors while management options are implemented in surrounding outdoor areas limited.

- it is unlikely to be acceptable for workers implementing management options to wear special clothing and personal protective equipment (PPE) if people remain in the area. Workers may be required to wear respirators since they may cause some resuspension by their actions. In this case, prior information would need to be provided to the watching public as to why similar protection was not provided for them.

2.5 Decision not to implement any management options

In some circumstances, authorities may decide that the best course of action is not to implement any management option. It is important that if this decision is taken it should always be accompanied by a monitoring strategy aimed at reassuring the local population. This option should be considered if the information available (measurements from environmental monitoring and results of assessments) indicate that the doses to people living in the area would be low. No judgement is made here on what would constitute a low dose. Other factors could make the decision not to implement any recovery action attractive, such as availability of limited resources or a very large area being affected. Table 2.5 gives the main advantages and disadvantages of carrying out no recovery.

Table 2.5 Advantages and disadvantages of carrying out no recovery options

Advantages
Implementing management options may be perceived as indicating that there is a problem even if doses are so low that they are being undertaken to provide reassurance.
Perception of affected area from outside may be better (i.e. incident is not perceived as a real problem; people are living normally). Economic blight may be less.
It sends out a clear message that risks are low and builds public confidence in decision-makers. Saying that the risk is low and still undertaking management options may give out a mixed message.
No waste is produced. Some clean-up options that may be undertaken for public reassurance can create a lot of contaminated waste, such grass cutting.
If management options are implemented the public may be reluctant to return to their homes.
Promotes return to normal living in the area.
Disadvantages
It requires very good communication with the community in order to convince people that risks are low and that they should accept the decision not to implement management options.
The implementation of management options is visible and may provide reassurance to people inside and outside the contaminated area.
It needs to be linked with a very rigorous monitoring strategy. Such a monitoring strategy might not be time or resource effective compared to the implementation of management options.
Not implementing any management options may send out a message that the response organisations and other organisations do not care enough about the community.
Decision-makers need to define the boundaries of the area in which management options are not implemented.
If restrictions have been placed on food consumption, there will need to be careful explanation of why these are required while no action is taken to deal with the contamination in inhabited areas.

2.6 References

Beresford NA, Voigt G, Wright SM, Howard BJ, Barnett CL, Prister B, Balonov M, Ratnikov A, Travnikova I, Gillett AG, Mehli H, Skuterud L, Lepicard S, Semiochkina N, Perepeliantnikova L, Goncharova N and Arkhipov AN (2001). Self-help countermeasure strategies for populations living within contaminated areas of Belarus, Russia and Ukraine. *Journal of Environmental Radioactivity*, 56, 215-239.

CONTENTS OF SECTION 3

3 DATASHEETS OF MANAGEMENT OPTIONS

3.1 The datasheet template

This Handbook considers 59 management options that may be implemented in inhabited areas following a radiological incident. Data have been presented systematically in a standard format to facilitate comparisons between options. The template design is based on that used in the STRATEGY project (Andersson *et al.*, 2003) but has been adapted to make it more appropriate for describing countermeasures for implementation in inhabited areas. The template includes the information that decision makers might want to consider when evaluating different countermeasures. These include:

- the objectives of the option
- a short description of the option
- constraints on its implementation
- effectiveness
- requirements
- waste generated
- doses received by those implementing the option
- costs
- side-effects
- practical experience.

Table 3.1 presents the template with a brief summary of the information that appears under each heading.

Values for all data quantities presented in the datasheets should be treated as indicative only. Real values will be dependent on the specific circumstances. The inclusion of these indicative values is purely to allow comparisons to be made between management options.

Table 3.1 Datasheet template*

Name of management option	
Likely Category	Categorisation of the management option based on Section 1.11.
Objective	Primary aim of the management option (e.g. reduction of external dose)
Other benefits	Secondary aims of the action (if any). For instance, the primary objective may be reduction of external dose, whereas an additional benefit may be a limited reduction in internal dose from food consumption.
Management option description	Short description of what the management option does and how to implement it.
Target	Type of area or surface where the management options will be implemented.
Targeted radionuclides	Radionuclide(s) or categories of radionuclides (e.g. alpha emitters) that the management option will protect against. Long-lived radionuclides are defined for the Handbook as radionuclides with a radioactive half-life greater than three weeks. Short-lived radionuclides are defined as radionuclides with a radioactive half-life of less than three weeks.
Scale of application	An indication of whether the option can be applied on a small or large scale (small scale ≤ 300 m^2; large scale > 300 m^2).
Time of application	Time relative to the accident/incident when the option is applied. Can be early phase (days), medium-term phase (weeks-months), or late phase (months-years).
Constraints	Provides information on the various types of restrictions that have to be considered before applying the management option.
Legal constraints	Laws referring to, for example, protection of the environment, cultural heritage protection, liabilities for property damage, protection of workers.
Environmental constraints	Constraints of a physical nature that prevent or restrict implementation (e.g. frost, soil type, slope and structure of land).
Effectiveness	Provides information on the effectiveness of the management option and factors affecting effectiveness.
Reduction in contamination on the surface	The reduction in activity concentration on the target surface at the time of implementation, i.e. a decontamination factor (DF).
Reduction in surface dose rates	The reduction in the dose rate above a surface.
Reduction in resuspension	The reduction in the resuspended activity concentration in air above the surface.
Technical factors influencing effectiveness	Technical factors that may influence the effectiveness of the method (e.g. surface material, evenness or slope of surface, weather conditions, soil type).
Social factors influencing effectiveness	Social factors that may influence the effectiveness of the method (e.g. reliance on voluntary behaviour, population behaviour).
Feasibility	Provides information on the equipment, infrastructure and skills needed to carry out the management option.
Equipment	Primary equipment for carrying out the management option.
Utilities and infrastructure	Utilities required in connection with implementing the management option (e.g. water and power supplies, distribution networks including roads).
Consumables	Consumables needed to implement the management option (e.g. fuel)
Skills	Level of skilled worker required to implement the option.
Safety precautions	Safety precautions necessary before workers can implement the option.
Waste	Some management options create waste, the management of which must be carefully considered at the time the management option is selected.
Amount and Type	Nature and volume of waste. Also, indication of whether waste is contaminated and whether contaminated waste can be segregated or minimised.
Doses	Provides information on how the management option leads to changes in the distribution of dose to individuals and populations
Averted doses	Likely reduction in external dose rates that could be received, recognising that any savings in dose are strongly dependent on the scenario.
Additional doses	Additional doses that could be received by workers implementing management options are included here. Potential exposure pathways are identified and a broad indication of dose-rates expressed as a multiplier of public doses is given.
Intervention costs	Provides information on the direct costs that may be incurred from implementing the management option (not including waste disposal).
Operator time	Time required for implementing the option per unit of the target.
Factors influencing costs	E.g. size and accessibility of target surface to be treated, availability of equipment and consumables within the contaminated area, requirement for additional manpower, wage level in the area, etc.
Side effects	Provides information on side effects of implementing the management option.
Environmental impact	Impact that a management option may have on the environment (e.g. with respect to pollution, land use).

Name of management option	
Social impact	Impact that an option may have socially (e.g. cleaned and renewed urban surfaces, affect population behaviour, loss of amenities, etc.)
Practical experience	Experience in carrying out the management option.
Key references	References to key publications leading to other sources of information.
Version	The version number of the datasheet.
Document history	The history of the document
*adapted from Brown *et al.*, 2007	

3.2 The datasheets

The datasheets are comprehensive, concise and intended to be generally applicable across Europe. The format and content are based largely on similar documents developed initially in the STRATEGY project (Andersson et al., 2003; Eged et al., 2003) and more recently within the EURANOS project itself (Brown et al., 2007). Some minor changes have been made to the datasheets presented here to improve consistency and compatibility with the Handbook. In accordance with the agreed terminology for the Handbook, the term countermeasure has been replaced with management option. Hyperlinks to sections of the Handbook or to other datasheets are indicated in the datasheets by blue underlined text.

3.2.1 Datasheet history

The history of the development of the datasheets is given in Table 3.2. Any additional relevant information, such as changes to the name of the management option is given in each datasheet in the document history field.

Table 3.2 Datasheet document history

Number	Document history
14,16, 17, 19, 22, 29, 30, 32, 35, 38-40 42, 46, 48, 52	**STRATEGY, 2006**. Originators: KG Andersson and J Roed (Risoe National Laboratory, Denmark. Contributors: K Eged, Z Kis, R Meckbach (GSF, Germany), G Voigt (IAEA), DH Oughton (Agricultural University of Norway), J Hunt and R Lee (University of Lancaster, UK), NA Beresford (Centre of Ecology and Hydrology, UK) and FJ Sandalls (UK). **STRATEGY peer reviewers**: B Johnsson (NFI/ISS, Sweden), SC Hoe (DEMA, Denmark), J Barikmo (Directorate for Nature Management, Norway), A Bayer (BfS, Germany), L Brynilsden (Ministry of Agriculture, Norway), O Harbitz (NRPA, Norway), D Humphreys (Cumbria County Council, UK) and K Mondon (FSA, UK). **UK Recovery Handbook 2005.** Originators: J Brown, GR Roberts and K Mortimer (HPA-RPD, UK). Updated for the UK and addition of new material. **EURANOS Recovery Handbook, 2007.** Developers: J Brown, K Mortimer (HPA-RPD, UK) and KG Andersson and J Roed (Risoe National Laboratory, Denmark). Up-dated and extended datasheets. **UK Recovery Handbook, 2008.** Developers: H Rochford and J Brown (HPA-RPD, UK). Up-dated EURANOS datasheets for the UK.
18, 20, 33, 37, 43, 45, 47, 50, 53-59	**STRATEGY, 2006**. Originators: KG Andersson and J Roed (Risoe National Laboratory, Denmark. Contributors: K Eged, Z Kis, R Meckbach (GSF, Germany), G Voigt (IAEA), DH Oughton (Agricultural University of Norway), J Hunt and R Lee (University of Lancaster, UK), NA Beresford (Centre of Ecology and Hydrology, UK) and FJ Sandalls (UK). **STRATEGY peer reviewers**: B Johnsson (NFI/ISS, Sweden), SC Hoe (DEMA, Denmark), J Barikmo (Directorate for Nature Management, Norway), A Bayer (BfS, Germany), L Brynilsden (Ministry of Agricultur, Norway), O Harbitz (NRPA, Norway), D Humphreys (Cumbria County Council, UK) and K Mondon (FSA, UK). **EURANOS Recovery Handbook, 2007.** Developers: J Brown, K Mortimer (HPA-RPD, UK) and KG Andersson and J Roed (Risoe National Laboratory, Denmark). Up-dated and extended datasheets. **UK Recovery Handbook, 2008.** Developers: H Rochford and J Brown (HPA-RPD, UK). Up-dated EURANOS datasheets for the UK.
8-13, 21, 24-27, 30, 32, 34, 41, 42,49, 51	**UK Recovery Handbook 2005.** Originators: J Brown, GR Roberts and K Mortimer (HPA-RPD, UK). **EURANOS Recovery Handbook, 2007.** Developers: J Brown, K Mortimer (HPA-RPD, UK) and KG Andersson and J Roed (Risoe National Laboratory, Denmark). Up-dated and extended datasheets. **UK Recovery Handbook, 2008.** Developers: H Rochford and J Brown (HPA-RPD, UK). Up-dated EURANOS datasheets for the UK.
28	**EURANOS Recovery Handbook, 2007.** Originators: J Brown, K Mortimer (HPA-RPD, UK) and KG Andersson and J Roed (Risoe National Laboratory, Denmark). **UK Recovery Handbook, 2008.** Developers: H Rochford and J Brown (HPA-RPD, UK). Up-dated EURANOS datasheets for the UK.
1-7, 15	**EURANOS Recovery Handbook, 2007.** Originators: J Brown, K Mortimer (HPA-RPD, UK) and KG Andersson and J Roed (Risoe National Laboratory, Denmark).

3.2.2 References

Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas. Riso-R-1396 (EN), Riso national laboratory, Denmark.

Brown J, Mortimer K, Andersson K, Duranova T, Mrskova A, Hänninen R, Kirchner G, Bertsch V, Gallay F and Reales N (2007). Generic Handbook for assisting in the management of contaminated inhabited areas in Europe following a radiological emergency. EURANOS (CAT 1)- TN(07)-02. Available online at http://www.euranos.fzk.de [Accessed on 24/10/08]

Eged K, Kis Z, Voigt G, Andersson KG, Roed J and Varga K (2003). Guidelines for planning interventions against external exposure in industrial area after a nuclear Accidnet. Part I: A holistic approach of countermeasure application. GSF-Bericht 01/03, GSF, Germany.

Table 3.3 Index of all management options for inhabited areas with hyperlinks to datasheets

Table 3.3 Index of all management options for inhabited areas with hyperlinks to datasheets

Back to list of options

1 Closing windows, doors and air ducts and controlling air exchange

Objective	To reduce air contaminant concentrations inside buildings during periods where outdoor concentrations are high, thereby reducing deposition indoors and longer term doses indoors from inhalation and inadvertent ingestion when people return to live in an area.
Other benefits	Inhalation doses indoors are reduced if people are sheltering in the buildings while the air exchange within the house is controlled. This is described in more detail in Datasheet 4, which covers sheltering of people.
Management option description	By closing windows and doors during the period of elevated outdoor air contaminant concentrations, indoor air concentrations can be reduced. If forced ventilation systems are equipped with effective aerosol filters, it can be advantageous to switch them on, as this will build up an overpressure in the building, so that virtually all air enters the dwelling through the ventilator filter. If there is no effective filter, ventilators must be closed off.
Target	All types of buildings.
Targeted radionuclides	All radionuclides, with varying effect according to physico-chemical forms. See Part III, Section 3 for information on radionuclides.
Scale of application	Any size.
Time of application	The early phase during the passage of the radioactive cloud, during which air contamination levels are high.
Constraints	
Legal constraints	Ownership and access to property to manage the option. Waste disposal of material from ventilator filters (high activity concentrations).
Environmental constraints	None
Effectiveness	
Reduction in time integrated air contamination	Air decontamination factor (DF) of 2 can be achieved over the period implemented for particles in the 0.5 μm range, a DF of 8 for particles in the 4 μm range, and a DF of 12 for elemental iodine gas. No effect on non-reactive gases, such as CH_3I.
Reduction in dose rate contribution	External gamma and beta dose rates from indoor deposition will be reduced by the value of the DF.
Reduction in resuspension	Resuspended indoor air concentrations will, during the period of implementation, be reduced by the value of the DF. Subsequent resuspended indoor air concentrations may also be reduced due to lower levels of contamination inside buildings.
Technical factors influencing effectiveness	Physico-chemical characteristics of contaminants (as distinguished above). Correct implementation of option. Time of operation (the longer the time between the appearance of the contaminated cloud and implementation of the option, the less effective the technique will be). Natural ventilation rate and furnishing of the dwelling. Higher effect achievable by sucking air from outdoors through a ventilator filter into the dwelling. Airing shortly after the cloud passage can further increase effect, but should be implemented with great care to ensure that the contaminated cloud has really gone.
Social factors influencing effectiveness	None
Feasibility	
Equipment	No equipment required.
Utilities and infrastructure	Roads for transport of equipment and waste.
Consumables	None.
Skills	Only a little instruction is likely to be required to communicate the objectives. Populations who have remained in the area and have not been required to shelter may be advised to implementation this option as a ‘self-help’ measure.
Safety precautions	None
Waste	
Amount and Type	If ventilator system with filter is used: type of filter (mass of filter likely to dominate) Specific activity can be high and require care in handling.
Doses	
Averted doses	Doses arising from indoor contaminants depositing over this period (inhalation and inadvertent ingestion) will be reduced by the values of the decontamination factors given above due to the reduction in indoor deposition. Doses from resuspension will also be reduced by the same factors as the indoor deposition.
Factors influencing averted dose	Time and duration of implementation.
Additional doses	This option is likely to be implemented by people who are managing the evacuated area. If

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1 Closing windows, doors and air ducts and controlling air exchange

	sheltering is in place, the people who are sheltering will implement the option under instruction (see Datasheet 4).
Intervention costs	
Operator time	10 minutes per building for establishing set-up. Team size: 1 person.
Factors influencing costs	
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	It may require a thorough communication effort to understand the benefits of this option, particularly the variant, where air is deliberately sucked through a ventilation system into the building from outside. Waste disposal may not be acceptable.
Practical experience	Many indoor-outdoor air concentration studies have been made in, e.g., Denmark, Germany and the USA, which support the data.
Key references	Andersson KG, Fogh CL, Byrne MA, Roed J, Goddard AJH and Hotchkiss SAM (2002). Radiation dose implications of airborne contaminant deposition to humans. *Health Physics* 82(2), 226-232. Roed J (1985). Relationships in indoor/outdoor air pollution. Risø-M-2476, Risø National Laboratory, Roskilde, Denmark. Roed J and Cannell R J (1987). Relationship between indoor and outdoor aerosol concentration following the Chernobyl accident. *Rad. Prot. Dosimetry* 21 (1/3), 107-110.
Version	2
Document history	See Table 3.2.

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2 Covering, storing or sealing personal / precious objects

Objective	To prevent contamination of personal/precious objects in inhabited areas so that they can continue to be used by the public without concern. Public reassurance is the primary objective.
Other benefits	Will significantly reduce the need to undertake decontamination of personal/precious objects. Objects stored in drawers and cupboards may still be subject to some deposition, although this is likely to be low. Will reduce exposure from contaminated objects.
Management option description	In advance of an atmospheric release of radioactive material, personal and precious objects can be covered, stored or sealed to prevent them being contaminated by deposited radionuclides. This is a precautionary countermeasure and could be carried out by the public as a self-help measure. Examples: covering items in cling-film; wrapping artefacts in bubble-wrap; covering furniture in dust sheets; sealing photographs, legal documents, bank books in plastic bags, placing jewellery in cases / drawers / cupboards, coverings/wrappings can be subsequently removed easily and disposed of.
Target	Personal possessions and precious objects.
Targeted radionuclides	All radionuclides. See Table 1.1 for information on radionuclides.
Scale of application	This is particularly suitable for small objects.
Time of application	Maximum benefit achieved if completed prior to the arrival of the radioactive plume.
Constraints	
Legal constraints	Ownership and access to precious objects in public buildings. Liabilities for possible damage to objects.
Environmental constraints	None
Effectiveness	
Reduction in contamination on the surface	This countermeasure will prevent or significantly reduce contamination of objects.
Reduction in surface dose rates	
Reduction in resuspension	
Technical factors influencing effectiveness	Correct implementation of the option: e.g. objects must be completely covered to avoid all contamination and carefully unwrapped to prevent contamination afterwards. Availability of covering material (e.g. cloth, cling-film). Time of implementation: objects must be covered/stored/sealed prior to deposition. Advance warning that area might be affected by the radioactive plume. If objects are placed in, e.g., cupboards, which are not completely air tight, the effectiveness will be lowest for particle contaminants in the size range 0.1-0.5 μm.
Social factors influencing effectiveness	This is primarily a self-help measure, so willingness of people to cover/store/seal their personal/precious object will influence the effectiveness.
Feasibility	
Equipment	None
Utilities and infrastructure	None
Consumables	Wrapping materials, dust sheets, etc. These must be available in the required quantities within individual buildings, as it is unlikely to be possible to leave buildings during the period that this option is implemented.
Skills	No special skills are required. The method could be implemented by the population as a self-help measure. Instructions on implementation from the relevant authorities would be required.
Safety precautions	Safe handling of objects.
Waste	
Amount and Type	Wrapping materials, dust sheets etc. Quantities could be up to a few kg m^{-2}.
Doses	
Averted doses	Averting doses is not the primary objective of this option. However, 100% of the external and resuspension doses from surface contamination of objects can be averted if objects are completely protected. Storage of objects in drawers and cupboards will significantly reduce subsequent external exposure from them.
Factors influencing averted dose	Prevention of recontamination of objects if other indoor surfaces are not cleaned.
Additional doses	This option is likely to be implemented by people who are living or working in the area and who are sheltering (see Datasheet 4).
Intervention costs	
Operator time	This is primarily a self-help measure.
Factors influencing costs	None

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2 Covering, storing or sealing personal / precious objects

Side effects	
Environmental impact	
Social impact	Protection of personal and precious objects will reduce the distress of having to clean or dispose of these items and will give reassurance that objects can be used without concern. Breakage of items may occur.
Practical experience	There is no readily available evidence of any practical experience of the use of this option for the recovery of radioactively contaminated inhabited areas.
Key references	
Version	2
Document history	See Table 3.2.

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3 Evacuation

Objective	To reduce exposure from airborne radioactive material as the contaminated plume passes through inhabited areas. Evacuation will also reduce external doses from beta and gamma emitters on outdoor surfaces during the evacuation period.
Other benefits	The evacuation of the population from the contaminated area may aid the implementation of other countermeasures.
Management option description	Evacuation is the temporary removal of a population out of highly contaminated areas. Evacuation may be to an unaffected area or an area with much lower levels of contamination. Evacuation may be triggered by dose criteria as part of the emergency plans for a nuclear establishment and may be considered to protect people in the following circumstances: as a precaution before any release of radioactivity occurs, this requires forewarning of the event and sufficient time to complete evacuation prior to the event, should it occur in scenarios where short term doses are projected to be large (of the order of a few tens of mSv or higher) when uncertainty in the progression of an accident event is likely to justify evacuation after a release has occurred to prevent short-term, relatively high external doses from deposited radionuclides. Evacuation may also be considered after a release to facilitate the implementation of decontamination and other countermeasures. Prior to evacuation, it is important to establish a criteria / strategy for returning the evacuated population. Too rapid a relaxation of evacuation, ie before the full pattern of environmental contamination has been assessed, could result in unnecessary exposure of the population. If a release occurs, the need to delay withdrawal of evacuation until a formal statement is given that the situation has been made safe, means that emergency plans should assume evacuation will last from several days up to perhaps a week or so.
Target	People living in inhabited areas that are likely to be or are affected by radioactive contamination released into the environment.
Targeted radionuclides	All radionuclides. Will give protection against high levels of short-lived radionuclides present in a release to atmosphere.
Scale of application	Any. However, it should be recognised that evacuation of large populations is difficult and requires a long time. Around nuclear sites, pre-planning for evacuation is typically limited to a few kilometres.
Time of application	Maximum benefit if people are evacuated before the contaminated plume reaches the area and evacuation continues until the release has stopped and any high levels of short-lived radionuclides deposited on the ground have reduced.
Constraints	
Legal constraints	Requires appropriate level of approval prior to implementation. Human rights concerns.
Environmental constraints	The nature of the environment and transport infrastructure could hinder the evacuation process. Temporary accommodation (e.g. evacuation centre, hotels, sports centres) would be required.
Effectiveness	
Reduction in contamination on the surface	This option will not reduce contamination levels in the environment
Reduction in surface dose rates	
Reduction in resuspension	
Technical factors influencing effectiveness	Speed of implementation and effectiveness of mechanism to deliver advice, eg. siren, phone call, radio, television, door-to-door. It should be noted that it can take several days to evacuate large numbers of people and this may significantly affect the effectiveness of the evacuation in reducing doses. Starting time of the evacuation. Availability of radiological data (monitoring strategy) and radiological assessments that will help to determine timing and scale of evacuation. Availability of geographic and demographic data. Availability of efficient, comprehensive and trusted communicators Size of area and population affected. Ease of evacuation, e.g. does area to be evacuated include hospitals, old people's homes, industrial processes. Weather (adverse conditions affect speed and safety of evacuation). The transport infrastructure, methods of transport and the time needed to evacuate different communities (villages, towns, districts). Evacuation route: evacuation through the plume will increase dose.

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3 Evacuation

	Effectiveness of pre-planning and decision making tools to identify appropriate evacuation area.
Social factors influencing effectiveness	Compliance of public to evacuate. Public's trust in authorities. Supervised visits to the evacuated area in order to retrieve possessions or deal with pets / animals may reduce the pressure for an early withdrawal of evacuation.
Feasibility	
Equipment	Organised transport (e.g. coaches) or self-evacuation by private vehicle. Road transport is likely to be available locally; however drivers may be unwilling to enter affected areas.
Utilities and infrastructure	Mechanism for initiating countermeasure: siren, phone call, radio, television, door-to-door. Receptive political infrastructure. Reception centre and/or accommodation. Prolonged evacuation requires the provision of more comfortable living conditions than many evacuation centres can provide. Medical and counselling services for the evacuated population including personal monitoring. Help line for worried relatives. Defined evacuation routes (congestion will affect speed of evacuation; evacuation through an ongoing release will unnecessarily expose the evacuating population). Mechanism to collect details of all those evacuated, for subsequent dose estimation and decisions on health follow-up programmes. Security provision for evacuated properties. Mechanism for those affected to input into decisions on the recovery strategy. Mechanism for direct verbal information and dialogue with the evacuees prior to their return to the area.
Consumables	Food and drink, bedding, clothing, products for personal hygiene, etc.
Skills	Expert moderation and organisational skills. Although inhabitants can evacuate themselves ('self-help'), strong organisation from authorities is essential to control this.
Safety precautions	Personal protective equipment (PPE) may be required for people entering the area to control the implementation of evacuation and transport people out of the contaminated area.
Waste	
Amount and Type	None
Doses	
Averted doses	Doses will be averted during the period of evacuation.
Factors influencing averted dose	The averted dose will be influenced by the level of exposure at the location used for evacuation and the duration of evacuation.
Additional doses	Additional doses would be received by those overseeing implementation of evacuation, transporting the evacuees out of the contaminated area and those providing security for the evacuated area.
Intervention costs	
Operator time	A large team of people would be required to issue advice, control the evacuated area and support the evacuated population.
Factors influencing costs	Size of evacuated population. Duration of evacuation. Effectiveness of pre-planning to aid efficiency of evacuation process.
Side effects	
Environmental impact	May be temporary change to land use.
Social impact	Can cause major upheaval and worry for the affected population, particularly for old and sick people. Moving of large numbers of people may lead to road traffic accidents and deaths. Restriction of freedom. Potentially high impact, in sense of building trust, but errors could lead to a loss of trust. Evacuated persons could become designated "victims" of incident. Designation of "The Evacuated Area" will affect economy of area e.g. tourism, business (even if area not affected by plume/ contamination). Community spirit may be heightened through the shared experience; therefore communities should be evacuated together (not split-up). Protection of important minority or cultural subgroups (e.g. reindeer herders). May encourage adjacent, unaffected populations to self-evacuate. Additional burden on medical and other local services.
Practical experience	Large numbers of people were evacuated from Pripyat and the surrounding exclusion zone

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3 Evacuation

	after the Chernobyl accident in the former Soviet Union.
Key references	National Radiological Protection Board (1990). Board Statement on Emergency Reference Levels. Doc NRPB **1**(4), Chilton, UK. International Atomic Energy Agency (1991). The International Chernobyl Project: An Overview. Report by an International Advisory Committee, IAEA, Vienna.
Version	2
Document history	See Table 3.2.

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4 Sheltering

Objective	To reduce exposure from airborne radioactive material as the contaminated plume passes through inhabited areas. Sheltering will also reduce external doses from beta and gamma emitters on outdoor surfaces during the sheltering period.
Other benefits	Sheltering a population in the contaminated area may aid the implementation of other countermeasures.
Management option description	"Sheltering" is the advice to a population to go indoors, remain indoors until further notice, close doors and windows and switch-off ventilation and air-conditioning systems. Further information on the effectiveness of changing ventilation within and building and the longer-term benefits of doing this are given in data sheet 5. Sheltering may be triggered by dose criteria as part of the emergency plans for a nuclear establishment and is likely to be considered to protect people in the following circumstances: an atmospheric release comprising mainly noble gases (i.e. where external irradiation from the plume is dominant) where short term doses in the absence of countermeasures are projected to be lower than those at which evacuation can be justified but high enough that some action to reduce short term doses is needed. to avoid evacuation through the plume from a very large release, in circumstances where evacuation is impractical as a pre-cursor to evacuation, so that it is easier to control evacuation The decision to withdraw sheltering will be influenced by the following. Duration: it is unlikely to be practicable to shelter a population for more than a day or so. Release status: partial withdrawal of sheltering (e.g. to re-unite families) or phased subsequent evacuation may be advised before formal advice is given that sheltering has been lifted, for example, before the incident site has been made safe. Availability of monitoring information on contamination levels (detailed monitoring in the sheltered area is likely to be the priority). Plans for a recovery strategy: decisions on any continuing protection of the sheltering population will need to be made. Lifting of sheltering should be accompanied by advice to ventilate buildings. Temporary sheltering may also be used while other recovery options are implemented to aid implementation and minimise any enhanced inhalation doses from resuspended material due to implementing other recovery options.
Target	People living in inhabited areas who are likely to be affected or are affected by radioactive contamination released into the environment.
Targeted radionuclides	All radionuclides. Will give protection against high levels of short-lived radionuclides present in a release to atmosphere.
Scale of application	Any. Around nuclear sites, pre-planning for sheltering (and other emergency countermeasures) is typically limited to a few kilometres.
Time of application	Maximum benefit if people are sheltered before the contaminated plume reaches the area and sheltering continues until the release has stopped. However, can also continue to be beneficial after the release has stopped by reducing external doses from high levels of short-lived radionuclides deposited on the ground .
Constraints	
Legal constraints	Requires appropriate level of approval prior to implementation. Human rights concerns.
Environmental constraints	The nature of the environment could hinder communication of the advice (to initiate sheltering or withdraw it).
Effectiveness	
Reduction in contamination on the surface	This option will not reduce contamination levels in the environment
Reduction in surface dose rates	
Reduction in resuspension	
Technical factors influencing effectiveness	Speed of implementation and effectiveness of mechanism to deliver advice, e.g. siren, phone call, radio, television, door-to-door. Ability to close down ventilation systems and shut windows and doors.
Social factors influencing effectiveness	Compliance of public to shelter and to remain indoors if sheltering lasts more than a few hours. Public's trust in authorities. Revisions of sheltering advice should be avoided (e.g. extent / duration). However, to maintain public confidence, it is likely to be more acceptable to implement sheltering over a larger area than may be justified on radiation protection grounds and then gradually reduce it than it is to have to increase it.

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4 Sheltering

Feasibility	
Equipment	None
Utilities and infrastructure	Receptive political infrastructure. Mechanisms to communicate with the sheltered population. For extended periods of sheltering, it may be necessary to visit the sheltered population to offer reassurance, food/drink and to reunite families. Medical and counselling services including personal monitoring.
Consumables	None
Skills	Excellent moderation and communication skills. Inhabitants would themselves, after having received advice, play a key role in implementation (‘self-help’).
Safety precautions	Personal protective equipment (PPE) may be required if people are entering the area to control the implementation of sheltering.
Waste	
Amount and Type	None.
Doses	
Averted doses	Averted doses are maximised if people are told to shelter before the plume arrives. Some particulate material will be removed by filtration in cracks and pores in the building surfaces as air penetrates the building. However, air concentrations (and hence inhalation dose) of non-depositing material (e.g. noble gases) will not be reduced. Indoor air concentrations (and inhalation doses during the period of sheltering) could typically be expected to be about a factor of 2 lower than those outdoors for iodine vapour and 1 µm particles and about a factor of 5 lower for 4 µm particles. The effectiveness will be greater for buildings with a lower natural air exchange rate. Further dose reductions can be achieved for non-depositing radionuclides (e.g. noble gases) by ventilating houses after the passage of the plume. While sheltering, external doses from radioactive material deposited outdoors are significantly reduced. The impact of this reduction on the external doses received will depend on the longevity of the radionuclides in the environment. Sheltering can be particularly effective in reducing external doses if the release comprises short-lived radionuclides. The reduction in external doses from outdoor contamination is dependent on the energy of the radionuclide emissions and the building structure and geometry. External gamma dose rates indoors from material deposited outdoors could typically be expected to be up to a factor of 10 lower than those outdoors for family homes. For multi-storey buildings, this factor could be as much as a factor of 100 lower. Cellars and basements offer very high protection. Beta particles of all energies will be stopped by most building construction materials. It should be noted that external doses will still be received from radionuclides deposited on indoor building surfaces and other objects and furnishings during sheltering.
Factors influencing averted dose	Some of the main factors affecting the dose reductions that could be achieved are: the building construction, particularly the thickness of the walls and roofs and the building materials used location of people within a building (protection is better on the ground floor (and in basements / cellars) and away from windows) timing of sheltering appropriate use of ventilation of the building aerosol size
Additional doses	Additional doses would be received by those overseeing implementation of sheltering and ensuring compliance if undertaken after the release has started.
Intervention costs	
Operator time	A large team of people could be required to issue advice, control sheltered area and support the sheltered population.
Factors influencing costs	None
Side effects	
Environmental impact	None
Social impact	Some negative impacts are: loss of economic output panic / worry in population claustrophobia / "cabin fever" imposed situation; restriction of liberty

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4 Sheltering

	sheltered population could become designated "victims" of the incident designation of "sheltered area" affects economy e.g. tourism, business (even if are not affected by plume / deposition) separating families, e.g. children unable to return home to their families from school until sheltering is lifted may encourage people to self-evacuate leading to loss of control of the affected population. Some positive impacts are: precautionary sheltering could engender public trust the lifting of sheltering should be seen as a positive step, i.e. the first step in the recovery process.
Practical experience	Sheltering is adopted for non-radiological incidents at a local level. There is very limited experience of sheltering large numbers of people.
Key references	National Radiological Protection Board (1990). Board Statement on Emergency Reference Levels. Doc NRPB **1**(4), Chilton, UK.
Version	2
Document history	See Table 3.2.

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5 Stable iodine tablets

Objective	To reduce exposure from the inhalation of airborne radioiodine as the contaminated plume passes through inhabited areas. Will also reduce doses from ingestion of radioiodine in the short term (limits on activity concentrations in food will control the exposures from ingestion of radioiodine in food in the medium and long term).
Other benefits	None.
Management option description	Stable iodine tablets (e.g. in the form of potassium iodate) are taken to prevent uptake of radioiodine by the thyroid gland. The advice to take stable iodine tablets may be triggered by dose criteria as part of the emergency plans for a nuclear establishment. This countermeasure should be considered in combination with the other emergency countermeasures, sheltering (data sheet 1) and evacuation (data sheet 2), as it will only provide protection from radioiodine taken into the body via inhalation or ingestion. The administration of stable iodine alone offers no protection from external irradiation of any kind or, indeed, internal irradiation from other radionuclides. It is not appropriate to administer stable iodine to provide protection against environmental contamination. Tablets may be pre-distributed (in the case of some fixed nuclear sites) or should be distributed as soon as an atmospheric release of radioiodine is expected, suspected, or confirmed. Priority for taking tablets should be given to new born babies, children under the age of 10, and pregnant and nursing women. Tablets may only be distributed to subsets of the population, eg infants and children. One dose of stable iodine will provide protection for around 24 hours. If a release of radioiodine is detected more than 24 hours after the first dose of stable iodine has been administered, evacuation should be considered in preference to administering a second dose. However, if evacuation is impractical, any sheltered population should be given priority for receiving additional tablets. Tablets should be accompanied by an information leaflet containing e.g. why the tablet is necessary, the dosage, when to take the tablets, side effects. Details of all those who received stable iodine should be recorded in case of subsequent health problems. Additionally, subsequent monitoring is required of the thyroids of children under 1 and those born within 9 months of the accident, if either the child or the mother received stable iodine.
Target	Sheltered / evacuated populations. Emergency services.
Targeted radionuclides	Radioiodine.
Scale of application	Any. Around nuclear sites, pre-planning for stable iodine (and other emergency countermeasures) is typically limited to a few kilometres.
Time of application	Administration should optimally be just before intake of radioiodine, although administration up to several hours after exposure can still achieve a substantial dose saving.
Constraints	
Legal constraints	Approval from health authority may be required.
Environmental constraints	Distribution, if tablets are not pre-distributed, could be hampered by the geography of affected area. Availability of tablets: numbers and proximity of supplies to site of incident.
Effectiveness	
Reduction in contamination on the surface	This option will not reduce contamination levels in the environment.
Reduction in surface dose rates	
Reduction in resuspension	
Technical factors influencing effectiveness	The dosage taken (i.e. was the correct dosage taken?). The time at which the tablet(s) were taken (i.e. were they taken before the plume arrived?). Effectiveness of mechanism to deliver advice, e.g. siren, phone call, radio, television, door-to-door and availability of efficient, comprehensive and trusted communicators. Effectiveness of distribution arrangements - pre-distribution versus distribution on the day or administration at a reception centre; are there enough tablets to go round?; who is going to distribute them?; maintenance of stocks (expiry dates). Effectiveness of pre-planning and decision making tools to identify appropriate areas for tablet distribution. If people are sheltering (see data sheet 1), this may hinder the distribution of tablets.
Social factors influencing effectiveness	Compliance of public (are people willing to take the tablets, will they read/understand the information leaflet correctly?). Public's trust in authorities.
Feasibility	

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5 Stable iodine tablets

Equipment	Vehicles to distribute tablets.
Utilities and infrastructure	The provision of a telephone help line. Mechanism for initiating countermeasure: siren, phone call, radio, television, door-to-door. Receptive political infrastructure. Medical and counselling services for the population including personal monitoring. Help line for worried relatives. Mechanism to collect details of all those who have taken stable iodine tablets, for subsequent dose estimation and decisions on health follow-up programmes.
Consumables	Enough stable iodine tablets for the affected population. Information leaflets that accompany tablets should include information about side affects and when to seek medical advice. Storage. Stable iodine tablets often have a fairly short storage life as they are classified as a medicine.
Skills	Expert organisational and communication skills.
Safety precautions	Personal protective equipment (PPE) may be required for people entering the area to distribute stable iodine tablets.
Waste	
Amount and Type	None.
Doses	
Averted doses	This countermeasure is 100% effective at blocking the uptake of radioiodine by the thyroid gland just a short time after the tablets are taken. One dose will continue to provide protection to the thyroid for around 24 hours. External doses will not be reduced, nor will internal doses from other elements.
Factors influencing averted dose	See 'Technical factors influencing effectiveness' above.
Additional doses	Depends on distribution arrangements. If distribution of tablets is required whilst a release is ongoing, those performing the distribution will receive inhalation and external doses.
Intervention costs	
Operator time	A large team of people would be required to issue advice, distribute the tablets if required and support the affected population.
Factors influencing costs	Availability of stocks of tablets. Size/distribution of potentially affected population. Effectiveness of pre-planning to aid efficiency of distribution of tablets.
Side effects	
Environmental impact	None
Social impact	Can cause major worry for the affected population, particularly for old and sick people, parents with young families and pregnant women. Side effects (real or perceived) of tablets may cause health concerns. People may be anxious if they have lost tablets or have not received "pre-distributed" tablets. The need to take tablets may heighten anxiety; however others may be reassured by taking tablets. Note that it should therefore be communicated that taking stable iodine is a positive protection measure. The taking of tablets may give people a false sense of security with respect to the other radiation hazards that may be present. Pre-distribution will offer the reassurance that people are helping themselves.
Practical experience	After the Chernobyl accident, 10.5 million potassium iodide tablets were distributed to children and 7 million adults in Poland.
Key references	National Radiological Protection Board (1990). Board Statement on Emergency Reference Levels. Doc NRPB **1**(4), Chilton, UK. National Radiological Protection Board (2001). Stable Iodine Prophylaxis. Recommendations of the 2nd UK Working Group on Stable Iodine Prophylaxis. Doc NRPB **12**(3), Chilton, UK. WHO (1989). Guidelines for iodine prophylaxis following nuclear accidents. Copenhagen, WHO Regional Office for Europe, Environmental Health Series No. 35. WHO (1999). Guidelines for iodine prophylaxis following nuclear accidents: update 1999. Geneva, WHO/SDE/PHE/99.6.
Version	2
Document history	See Table 3.2.

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6 Using vacuum cleaners as air cleaners

Objective	To reduce contaminant concentrations in air inside buildings when outdoor concentrations in air are high, thereby reducing doses from inhalation and from deposition indoors.
Other benefits	Subsequent resuspension and contact transfer of contamination indoors will be reduced. Indoor deposition will also be reduced.
Management option description	By leaving a vacuum cleaner switched on indoors in a room occupied by people, the indoor air is dragged through the filter bag, which acts as an aerosol filter, hence reducing activity concentrations in the 'cleaned' air. The vacuum cleaner is placed in a single location without attachments (ie not used as a cleaning device). It should be noted that a dust-filled bag has been found to be a more efficient filter than an empty bag and so the 'dust collection' receptacle should not be changed. The effectiveness can be enhanced if the air is sucked indoors from outdoors, thereby building up an overpressure, so that nearly all air enters the dwelling through the vacuum cleaner filter. However, this requires a reasonably air-tight fit of the pipe between the inside and outside of the building, e.g., through a window. It should be noted that this countermeasure generates a lot of noise.
Target	Only likely to be feasible for use in residential buildings. However, could be used in offices, schools and other buildings where people may be sheltering.
Targeted radionuclides	All radionuclides, with varying effect according to physico-chemical forms. However, effect is negligible on non-reactive gases.
Scale of application	Any size.
Time of application	During passage of the radioactive cloud, when air contamination levels are high.
Constraints	
Legal constraints	Ownership and access to property (if not implemented by home owners). Waste disposal of filters (high concentrations).
Environmental constraints	None.
Effectiveness	
Reduction in time integrated air contamination	Air decontamination factor (DF) of 9 can be achieved inside a building over the period during which a vacuum cleaner is operated given an air filter efficiency of 0.97, particles in the 0.5 µm range and a suction speed of 60 m3 per h.
Reduction in surface dose rates	External gamma and beta dose rates from indoor deposition and inhalation dose rates will be reduced by the value of the DF during the period of implementation.
Reduction in resuspension	Resuspended indoor air concentrations will, during the period of implementation, be reduced by the value of the DF. Subsequent resuspended indoor air concentrations may also be reduced due to lower levels of contamination inside buildings.
Technical factors influencing effectiveness	Vacuum cleaner type (filter, suction speed). With modern cleaners with hepa filters, the effectiveness will probably be greater. Physico-chemical characteristics of contaminants. Elemental iodine concentrations will be reduced greatly; however, there will be little effect on organic iodine. Effectiveness for larger particles will be higher than the value given above. Time of operation (the longer the time between the appearance of the contaminated cloud and implementation of the option, the less effective the technique will be). Natural ventilation rate and furnishing of the dwelling. Higher effect by sucking air from outdoors but sealing of pipe between outdoors and indoors needs to be effective. Airing shortly after the cloud passage can further increase the effectiveness but this should be implemented with great care to ensure that the contaminated cloud has really gone.
Social factors influencing effectiveness	It may be hard to effectively communicate the benefits of this option.
Feasibility	
Equipment	Ordinary household vacuum cleaner with filter.
Utilities and infrastructure	Roads for transport of equipment and waste.
Consumables	Power supply. Filter bags.
Skills	Only a little instruction is likely to be required. The method could be implemented by the population as a self-help measure. However, clear communication of the objectives will be needed so that people are not confused over the use of the vacuum cleaners.
Safety precautions	None.
Waste	
Amount and Type	Amount: mass of filter likely to dominate. Type: paper filter with dust. Specific activity can be high and require care in handling.

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6 Using vacuum cleaners as air cleaners

Doses	
Averted doses	No estimates made. However, an indication of the reductions in inhalation dose received during implementation can be obtained from the values given above.
Factors influencing averted dose	Fraction of time spent indoors during the time the radioactive plume passes overhead and for a short period afterwards. Time and duration of implementation.
Additional doses	This option is likely to be implemented by people who are living or working in the area and who are sheltering (see Datasheet 4).
Intervention costs	
Operator time	10 minutes per residential building for setting-up the vacuum cleaner. Team size: 1 person.
Factors influencing costs	The following influence the time taken to implement the option and hence labour costs: type of vacuum-cleaner used access and amount of contents in building.
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	It may be hard to effectively communicate the benefits of this option, particularly the variant where air is deliberately sucked into the building from outside. Contamination of vacuum cleaners and the collection of the waste filters may not be acceptable.
Practical experience	Small scale experiments have been made in Denmark.
Key references	Roed J (1985). Relationships in indoor/outdoor air pollution. Risø National Laboratory, Risø-M-2476.
Version	2
Document history	See Table 3.2.

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7 Wearing simple masks for respiratory protection

Objective	To reduce dose from inhalation of radioactive material in the plume and to reduce inhalation of resuspended material from contaminated surfaces in an inhabited area during periods where activity concentrations are high.
Other benefits	Intervention personnel required to work in areas of low contamination may be reassured by wearing simple masks.
Management option description	Masks are issued to emergency service personnel and members of the public in areas likely to be contaminated or that have been contaminated by radioactive material. The wearing of masks would be in addition to sheltering advice to the public. For further information on sheltering, see Datasheet 4. Such masks are not a substitute for full respiratory protection equipment that would be used in highly contaminated areas. It should be recognised that in order to ensure effectiveness, individual fitting is required. Reliance should not be placed on masks reducing inhalation doses if they have not been individually fitted and advice to wearers has not been issued.
Target	People who live in or who are required to enter an area likely to be affected or that has been affected by radioactive contamination.
Targeted radionuclides	Radionuclides attached to aerosols and reactive gases. Aimed particularly at saving dose from radionuclides in the emergency phase during the passage of the radioactive plume. Will not protect against non-reactive gases. See Part III, Section 3 for information on radionuclides.
Scale of application	Any size, although much easier to implement on a small scale.
Time of application	Maximum benefit if masks are worn before airborne radioactive material arrives in the area.
Constraints	
Legal constraints	Requires appropriate level of approval prior to implementation. Simple masks are not a substitute for full respiratory protection equipment required by those required to enter / work in highly contaminated areas.
Environmental constraints	None.
Effectiveness	
Reduction in contamination on the surface	This option will not reduce contamination levels in the environment.
Reduction in surface dose rates	
Reduction in resuspension	
Technical factors influencing effectiveness	The material from which the masks are constructed. The timeliness of implementing the measure. Masks must fit correctly: face shape and size, facial hair, spectacles can affect the fit of masks. Masks will make normal voice communication more difficult.
Social factors influencing effectiveness	The willingness and ability of people to wear the masks.
Feasibility	
Equipment	Masks. Vehicles to distribute the masks.
Utilities and infrastructure	Roads to enable mask distribution.
Consumables	None.
Skills	Excellent communication skills are needed if masks are to be issued to the public to ensure that the objectives are clear and that people are not scared. Although distribution of masks is carried out by authorities, the effective use of the masks has an element of 'self-help'.
Safety precautions	None.
Waste	
Amount and Type	The masks will require disposal after use.
Doses	
Averted doses	For aerosols, the protection offered will be least effective for particles in the size range 0.1 – 2.0 µm, where the reduction in dose rates is likely to be 10 – 25%. For larger and smaller particles, the reduction in dose-rate could be up to 90%. For reactive gases, reductions in dose-rates could be between 10% and 90%.
Factors influencing averted dose	See 'Technical factors influencing effectiveness' above.
Additional doses	Unlikely to be any additional doses to people implementing this option.
Intervention costs	
Operator time	Not estimated.
Factors influencing costs	Number of masks required.

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7 Wearing simple masks for respiratory protection

	Administration / communication costs.
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	Panic / worry in population. The precautionary issue of masks may engender trust in authorities. If masks are not fitted properly, wearing them may give rise to a false sense of security with respect to their effectiveness.
Practical experience	The use of simple masks has been used in several recovery operations in the former Soviet Union after the Chernobyl accident. However, there is no readily available evidence of any practical experience of its use during the emergency phase of an accident.
Key references	
Version	2
Document history	See Table 3.2.

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8 Permanent relocation from residential areas

Objective	To reduce external gamma and beta doses from material deposited on surfaces and inhalation doses from material resuspended within contaminated inhabited areas.
Other benefits	Any necessary management options will be implemented more easily whilst the population are absent from the area.
Management option description	The removal of people from a contaminated area on a permanent basis. Resettlement may occur in the future. High social and economical impact.
Target	People living in contaminated residential areas.
Targeted radionuclides	Only long-lived radionuclides.
Scale of application	Any. Unlikely to be feasible for very heavily populated areas.
Time of application	Maximum benefit soon after deposition or during the emergency phase
Constraints	
Legal constraints	Compensation for homes, possessions and possible loss of earnings. Building new residential areas and waste facilities will need to meet legislation and authorisation may need to be granted.
Environmental constraints	None
Effectiveness	
Reduction in contamination on the surface	Will not reduce contamination in the restricted area
Reduction in surface dose rates	
Reduction in resuspension	
Technical factors influencing effectiveness	None
Social factors influencing effectiveness	Compliance: people cannot be forced to leave their homes Individuals re-entering the area
Feasibility	
Equipment	Transport vehicles for moving people and possessions
Utilities and infrastructure	New housing. Infrastructure to support relocated populations: schools, doctors, social services, support for those seeking employment etc.
Consumables	Fuel and parts for vehicles and other transport
Skills	Drivers. Security personnel may be required to support drivers. Removal personnel. Supportive administration at new site.
Safety precautions	None
Waste	
Amount and Type	None
Doses	
Averted doses	Doses will be reduced by 100% for the people relocated if they are moved away from the affected area.
Factors influencing averted dose	Level of exposure at new location. Compliance with relocation as people cannot be forced to leave their homes. People re-entering area.
Additional doses	People implementing permanent relocation could be exposed to: • external exposure from deposited radioactive material • inhalation of resuspended radioactivity
Intervention costs	
Operator time	Assuming people are moved about 1 hour away to a 'holding' location, it is estimated that 1 person can relocate about 60 people every 4 hours. Further effort will be required to relocate people and their possessions to a new area.
Factors influencing costs	Weather. Type of vehicles used. Number of vehicles available. Ease of access and transport route. Distance people have to be moved. Numbers of people being relocated.
Side effects	
Environmental impact	Building new residential areas will impact on the environment, e.g. need to build new

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8 Permanent relocation from residential areas

	infrastructure, changes of land use, generation of waste, etc.
Social impact	Disruption in affected communities will be very large (those moved and those in receiving communities). Fragmentation of communities.
Practical experience	Relocation after the Chernobyl accident.
Key references	IAEA (1991). *The international Chernobyl project: an overview*. Report by an International Advisory Committee, IAEA, Vienna.
Version	2
Document history	See Table 3.2.

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9 Prohibit public access to non-residential areas

Objective	To reduce external gamma and beta doses from material deposited on surfaces and inhalation dose from material resuspended from surfaces within contaminated non-residential areas.
Other benefits	Any necessary recovery options will be implemented more easily whilst the population are absent from the area. Reduction in ingestion doses from consuming wild foods collected from recreational areas, e.g. woods, countryside.
Management option description	For non-residential areas accessed by the public (e.g. parks, recreational areas), only a total prohibition on access will be enforceable. Any partial restriction cannot be controlled and it will not be possible to control the doses received by members of the public. Could be implemented in the short or long term. Recreational areas are unlikely to have a high priority for clean-up and so restricting access may be necessary prior to any clean-up being implemented. Land is only likely to be fenced-off in the long term if it is privately owned. Public land would be controlled with notices and barriers on main access routes (if practicable). Temporary prohibition of access to non-residential areas may be enforced while clean-up is being implemented.
Target	People living in and visiting contaminated areas.
Targeted radionuclides	All radionuclides. Particularly short-lived radionuclides.
Scale of application	Any scale.
Time of application	Maximum benefit if carried out soon after deposition. Can be applied at any time and for any duration of time. May be implemented while other management options are implemented.
Constraints	
Legal constraints	May require legislation to restrict access to land, depending on ownership.
Environmental / technical constraints	None
Effectiveness	
Reduction in contamination on the surface	If people comply, this option is fully effective at reducing doses from the areas where access is prohibited. This option will not reduce contamination levels in the restricted area.
Reduction in surface dose rates	
Reduction in resuspension	
Technical factors influencing effectiveness	Effective exclusion of people from an area may be difficult to demonstrate. Success of barriers and fences (if used).
Social factors influencing effectiveness	Compliance: an effective public information strategy will be essential.
Feasibility	
Equipment	None
Utilities and infrastructure	None
Consumables	Notices, signs, barriers etc.
Skills	None
Safety precautions	None
Waste	
Amount and Type	None
Doses	
Averted doses	Doses that would have been received from the prohibited areas will be reduced by 100% if access is effectively stopped.
Factors influencing averted dose	Complying with access prohibition. Population habits – for example, if people didn't spend time in areas where access is prohibited, this option will not reduce their overall doses. Success of cordons (if used).
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment • enhanced resuspension of activity deposited in the environment No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.
Intervention costs	
Operator time	Labour for implementing option.
Factors influencing costs	Size of areas(s) where access is restricted. Possible need to regulate access prohibition in some areas.

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9 Prohibit public access to non-residential areas

Side effects	
Environmental impact	Prohibition of access to countryside may benefit fauna and flora.
Social impact	Loss of public amenities. Changed perception of the countryside / other recreational areas.
Practical experience	In the Former Soviet Union after the Chernobyl incident. In the UK as a consequence of foot and mouth disease.
Key references	N/A
Version	2
Document history	See Table 3.2.

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10 Restrict workforce access (time or personnel) to non-residential areas

Objective	To enable the population to remain in the area by keeping essential services and infrastructure operating.
Other benefits	Any necessary recovery options will be implemented more easily whilst the population are absent from the area.
Management option description	Work environments can be controlled (both the people who are allowed to enter a workplace and the time that workers spend there). Employers have duty of care towards their employees; therefore it will not generally be acceptable for employees to work in a contaminated area where it has been deemed unacceptable for people to live. In this case access is likely to be prohibited. For employees who are providing essential services, restricted access can be used with close control on the doses. May be enforced while recovery options are being implemented.
Target	People working in contaminated areas.
Targeted radionuclides	All radionuclides. Particularly short-lived radionuclides.
Scale of application	Any size of workplace.
Time of application	Soon after deposition but may continue for some time. May be implemented while recovery options are being implemented.
Constraints	
Legal constraints	Compensation for lack of earnings. Duty of care of employers.
Environmental constraints	None
Effectiveness	
Reduction in contamination on the surface	Effective in controlling doses to an essential workforce as long as people comply and controls are enforced. This option will not reduce contamination levels in the restricted area.
Reduction in surface dose rates	
Reduction in resuspension	
Technical factors influencing effectiveness	None
Social factors influencing effectiveness	Compliance with restricted access.
Feasibility	
Equipment	Monitoring equipment for workforce going into area.
Utilities and infrastructure	System to control and monitor doses to workforce.
Consumables	None
Skills	Ability to manage radiation protection of the workforce.
Safety precautions	Monitoring health and safety when there is only a skeleton workforce in an establishment.
Waste	
Amount and Type	None
Doses	
Averted doses	Effective in controlling doses to an essential workforce. Doses to workers who are required to be work in contaminated area will be closely monitored; they will receive an additional dose compared with other members of the public.
Factors influencing averted dose	Complying with restricted access.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment • enhanced resuspension of activity deposited in the environment
Intervention costs	
Operator time	Labour for implementing option.
Factors influencing costs	Size of area(s) where access is restricted.
Side effects	
Environmental impact	Buildings and outdoor areas may not be maintained.
Social impact	Loss of public amenities. Acceptability of key workers receiving additional doses.
Practical experience	None
Key references	N/A
Version	2
Document history	See Table 3.2.

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11 Temporary relocation from residential areas

Objective	To reduce external gamma and beta doses from material deposited on surfaces and inhalation doses from material resuspended from surfaces within contaminated inhabited areas.
Other benefits	Management options will be more easily implemented whilst the population are absent.
Management option description	The removal of individuals from a contaminated area on a temporary basis. It is likely that people would be moved to an area that is sufficiently far outside the contaminated area that doses are minimal but is near enough for people to commute to their normal places of work. Should be time bound. May also be considered whilst recovery options are underway.
Target	People living in contaminated areas.
Targeted radionuclides	All radionuclides. Particularly useful for short-lived radionuclides.
Scale of application	Any number of people. Easier to implement on a small scale.
Time of application	Maximum benefit if people are moved out soon after deposition or are evacuated during the emergency phase and do not return.
Constraints	
Legal constraints	Compensation for people moved and possible lack of earnings. Provision of security for empty buildings.
Environmental constraints	Maintenance of buildings and environment for longer term temporary relocation.
Effectiveness	
Reduction in contamination on the surface	If people comply, this option is fully effective at removing all doses during the period of relocation. It will not reduce contamination in the restricted area.
Reduction in surface dose rates	
Reduction in resuspension	
Technical factors influencing effectiveness	None
Social factors influencing effectiveness	Compliance: people cannot be forced to leave their homes. Ability to prevent subsequent unauthorised access.
Feasibility	
Equipment	Transport for moving people and possessions.
Utilities and infrastructure	Alternative accommodation / housing. Infrastructure to support relocated populations: schools, doctors, social services etc. Security services for area that has been relocated.
Consumables	Fuel and parts for vehicles and other transport.
Skills	Drivers. Security personnel may be required to support drivers.
Safety precautions	None
Waste	
Amount and Type	No waste produced
Doses	
Averted doses	Doses will be reduced by 100% during the period of relocation if people are moved fully away from the affected area.
Factors influencing averted dose	Level of exposure at new location. Compliance with relocation.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment • enhanced resuspension of activity deposited in the environment
Intervention costs	
Operator time	Assuming people are moved about 1 hour away, it is estimated that one person can relocate 60 people every 4 hours.
Factors influencing costs	Weather. Type of vehicle used. Number of vehicles available. Ease of access and transport route. Distance people have to be moved. Numbers of people being move. Availability of appropriate accommodation.
Side effects	
Environmental impact	Increasing the size of the population in the area where people are temporarily relocated may

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11 Temporary relocation from residential areas

	impact on the environment, e.g. amount of general waste generated, increased traffic.
Social impact	Disruption in the affected communities (those moved and those in the receiving communities). Fragmentation of communities. Additional burden on schools, medical and recreational services.
Practical experience	Some experience of temporary relocation for other incidents at a local level. Relocation after the Chernobyl accident.
Key references	Morrey M and Allen P. The role of social and psychological factors in radiation protection after accidents. *Radiation Protection Dosimetry*, 68**,** (3/4), 267-271. Oughton DH, Bay I, Forsberg E-M, Hunt J, Kaiser M and Littlewood D (2003). Social and ethical aspects of countermeasure evaluation and selection – using an ethical matrix in participatory decision making. Deliverable 4 of the STRATEGY project. Agricultural University of Norway, Norway.
Version	2
Document history	See Table 3.2.

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12 Demolish buildings

Objective	To remove contamination associated with buildings. Demolishing buildings will reduce external gamma and beta doses in the future if the area is resettled as long as other outdoor surfaces have also be decontaminated or removed.
Other benefits	Will prevent removal of contaminated materials for use elsewhere.
Management option description	Buildings can be demolished by crane and ball or by pneumatic chisel. Dust levels will need to be controlled using water spray during demolition to keep doses to workers at an acceptable level. The building can be encapsulated in a scaffolding structure, faced with panels, equipped with a HEPA filtered ventilation system to further control dust. Foundations may be removed (by jack hammers or other means) depending on the size of the building, if required. Will only be acceptable if the surrounding environment is also contaminated and is to be subsequently cleaned. Surrounding ground surfaces must also be decontaminated or removed. Checks for asbestos before buildings are demolished should be ensured.
Target	Highly contaminated buildings in an area where doses are too high for people to live. May also be appropriate for an incident involving the dispersion of contamination inside a building.
Targeted radionuclides	All long-lived radionuclides. Should not be considered for removal of short-lived radionuclides alone.
Scale of application	Any size.
Time of application	Not important.
Constraints	
Legal constraints	Compensation for demolition of building. Use on listed and other historically important buildings Solid waste disposal legislation Responsibility for relocating residents or users.
Environmental constraints	High winds will complicate matters because of the amount of dust likely to be produced.
Effectiveness	
Reduction in contamination on the surface	Option will be 100 % effective in removing contamination on building surfaces if all debris is removed and contamination is not spread during demolition process.
Reduction in surface dose rates	Dose rates from contamination on the buildings will be eliminated. However, it should be noted that the buildings also provided shielding against radiation from other sources in the environment and so to reduce overall dose rates from the surrounding land, this will also need to be decontaminated.
Reduction in resuspension	None
Technical factors influencing effectiveness	Amount of dust produced during demolition. Removal of all debris. Weather conditions. Consistency in effective implementation of option over entire area. Control of dust produced during demolition. Reduction of dose contributions from surrounding ground surfaces. Construction of new buildings.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Crane and ball. Scaffolding. Pneumatic chisel. HEPA filtered ventilation system. Jackhammer. Transport vehicles for equipment and waste.
Utilities and infrastructure	Roads for transport of equipment, materials and waste. Water supply.
Consumables	Water. Acrylic paint. Fuel and parts for equipment and vehicles.
Skills	Skilled personnel essential for demolition of buildings.
Safety precautions	Safety helmets. Safety boots. Safety goggles.

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12 Demolish buildings

<table>
<tr><td></td><td colspan="3">Respiratory protection is essential, because of dust quantities.
Appropriate safety measures and respiratory protection will be required if asbestos is present.</td></tr>
<tr><td colspan="4">Waste</td></tr>
<tr><td>Amount and Type</td><td colspan="3">*Amount:* 7 10^1 kg m^{-2}
Type: Rubble and other building fragments.</td></tr>
<tr><td colspan="4">Doses</td></tr>
<tr><td>Averted doses</td><td colspan="3">It is unlikely that people will be living in buildings that are to be demolished due to high contamination levels. Therefore, there will not be an immediate reduction in doses to individuals. 100 % reduction in doses from contamination on the buildings after demolition may enable resettlement in the area in the future.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="3">Consistency in effective implementation of option over entire area.
Control of dust produced.
Decontamination of surrounding ground surfaces.</td></tr>
<tr><td>Additional doses</td><td colspan="3">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• enhanced resuspension of activity deposited in the environment
• inhalation of dust generated
• *inadvertent ingestion of dust from workers' hands*
Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE.
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="4">Intervention costs</td></tr>
<tr><td rowspan="3">Operator time</td><td></td><td>Crane & ball</td><td>Secondary containment & pneumatic chisels</td></tr>
<tr><td>Work rate (m^2/team.hr)</td><td>5</td><td>0.5</td></tr>
<tr><td>Team size (people)</td><td>4</td><td>4</td></tr>
<tr><td>Factors influencing costs</td><td colspan="3">Weather.
Size of building.
Type of equipment used.
Building construction materials.</td></tr>
<tr><td colspan="4">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="3">The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.</td></tr>
<tr><td>Social impact</td><td colspan="3">Destruction of inhabited area.
Distress caused by loss of homes or amenities.
Acceptability of aesthetic changes to area.
Acceptability of production and disposal of large amounts of waste.</td></tr>
<tr><td>Practical experience</td><td colspan="3">Tested on selected houses in the Former Soviet Union (e.g., in Gomel, Belarus) after the Chernobyl accident.</td></tr>
<tr><td>Key references</td><td colspan="3">Morgan CJ (1987). Methods and cost of decontamination and site restoration following dispersion of plutonium in a weapon accident. Aldermaston, AWE, SCT Laboratory.
Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p.</td></tr>
<tr><td>Version</td><td colspan="3">2</td></tr>
<tr><td>Document history</td><td colspan="3">See Table 3.2.</td></tr>
</table>

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13 Firehosing

Objective	To reduce external gamma and beta doses from contamination on external walls and roofs of buildings within inhabited areas, and reduce inhalation dose from material resuspended from these surfaces.
Other benefits	Will remove contamination from external building surfaces.
Management option description	For normal sized residential housing, a hydraulic platform can be used to provide access to the front and rear walls and roofs of buildings. Dust creation during implementation is unlikely to be a problem and so methods are not required to reduce the resuspension hazard to workers. Recontamination of surfaces by resuspended contaminants will be insignificant, so repeated application is not required. **Roofs:** It is unlikely that it will be practicable to collect all the water used for firehosing. Collection of water from roofs can be aided by modifying guttering and drainpipes, so that the collected waste is fed into collection tanks, where it may be filtered (most of radioactivity will be associated with the solid phase). If no active means are adopted to collect the water, some will soak into the ground or pass directly into the drains or to soak-aways via gutters and drainpipes. **Walls:** it is unlikely to be practicable to collect the waste water and associated contamination. If it is practicable to collect the waste water, this can be done using PVC sheets draped between scaffolding and the wall. The bottom of the sheet hangs in a metal trough sealed to the wall with pitch. Water flows into the trough and a pump delivers the water to collection tanks where it is then filtered and pumped to delay tanks. **Ground:** If run-off has occurred, implementation of options to the surrounding ground surfaces should also be considered after firehosing has been implemented. If the implementation of any other options to the surrounding ground surfaces is planned, firehosing of walls and roofs should be implemented first.
Target	External walls and roofs of buildings.
Targeted radionuclides	All radionuclides. Short-lived radionuclides: only if implemented quickly.
Scale of application	Any size.
Time of application	Maximum benefit within 1 week of deposition when maximum dust/dirt remains on surfaces.
Constraints	
Legal constraints	Liabilities for possible damage to property (e.g. flooding). Use on listed and other important buildings. Ownership and access to property. Disposal of contaminated water via public sewer system.
Environmental constraints	Severe cold weather (snow or ice). Roof constructions must be water resistant.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of 1.3 can be achieved if this option is implemented within 1 week of deposition and before significant rain (rain is likely to remove more contamination from roofs than from walls). Repeated application is unlikely to provide any significant increase in DF. In the short term, the quoted DF can be considered to be same for all radionuclides, with the exception of elemental iodine and tritium for which thorough washing of impermeable surfaces will lead to virtually full removal.
Reduction in surface dose rates	External gamma and beta dose rates from the decontaminated surfaces will be reduced by approximately the value of the DF.
Reduction in resuspension	Resuspended activity in air will be reduced by the value of the DF.
Technical factors influencing effectiveness	Consistent application of water over the contaminated surface. Dust levels on surface / moss on roofs. Type of surface. Rough surfaces eg roof tiles may trap contamination which is harder to remove. Number of windows (windows easier to clean). Amount of buildings in the area. Careful cleaning: contamination needs to be washed from walls and roofs, not just 'moved around' the surface. Special care should be taken to clean roof gutters and drain pipes. Extra care should be taken to clean the lower part of walls as this is the surface that will provide the greatest dose to an individual near the building. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.

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13 Firehosing

Feasibility

Equipment	Fire-tender and hydraulic platform with mounted hoses. Scaffolding. PVC sheets. Trough. Tanks. Spate pumps and filters. Transport vehicles for equipment and waste.
Utilities and infrastructure	Water and power supplies. Roads for transport of equipment and waste. Public sewer system.
Consumables	Water. Fuel and parts for vehicles.
Skills	Skilled personnel essential to operate fire-engines and hoses.
Safety precautions	Lifeline. Safety helmets. Water-resistant clothing should be recommended, particularly for strongly contaminated areas. May need PPE to protect against inhaling water spray. Precautions are needed to ensure that people making connections to mains water supplies do not inadvertently contaminate the water supply, e.g. by back-flow from vessels containing radioactivity or other contaminants, or operate hydrants in a way that disturbs settled deposits within the water main system.
Waste	
Amount	1 10^{-1} – 2 10^{-1} kg m^{-2} solid and 50 l m^{-2} water
Type	Dust and water. Unlikely to be possible to collect water from firehosing walls.
Doses	

	Cs-137 (% reduction in external dose)				Pu-239 (% reduction in resuspension dose)			
Averted dose	Over 1st year		Over 50 years		Over 1st year		Over 50 years	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
	5-10	<5	5-10	<5	0	<5	<5	<5

The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area. The estimated dose reductions do not include any potential future doses that may arise if contaminated water enters the drainage system and subsequently the wider environment (see Appendix C for further information).

Factors influencing averted dose	Population behaviour in the area. Amount of buildings in the area i.e. environment type/land use. Consistency in effective implementation of option over a large area. Careful cleaning. Contamination needs to be washed from walls and roofs, not just 'moved around' the surface. Special care should be taken to clean roof gutters and drain pipes. Extra care should be taken to clean the lower part of walls as this is the surface that will provide the greatest dose to an individual near the building. The area on the ground surrounding the building should be treated after treating the building if waster is not collected. Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • enhanced resuspension of activity deposited in the environment • inhalation of dust and water spray generated • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included.
Intervention costs	

Operator time		Walls	Roofs
	Work rate (m^2/team.hr)	8 10^2 – 1 10^3	1 10^2

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13 Firehosing

	Team size (people)	Up to 5	1
Factors influencing costs	Weather. Building size. Type of equipment used. Access. Proximity of water supplies. Use of personal protective equipment (PPE) by workers.		
Side effects			
Environmental impact	Firehosing will create contaminated waste water. Appropriate monitoring in the sewage treatment plant and any subsequent disposal of sludge and water will minimise environmental impact. The disposal or storage of waste from this option may have an environmental impact. It may be minimised through the control of any disposal route and relevant authorisations. If waste water is not collected, some of it will run onto other surfaces (roads, soil, grass etc), resulting in a transfer of contamination which may require subsequent clean-up, generating more waste. It is important that firehosing of buildings is implemented before recovery options are implemented on surrounding ground surfaces.		
Social impact	Acceptability of active disposal of contaminated waste water into the public sewer system. Firehosing of buildings will make an area look clean; implementation may give public reassurance.		
Practical experience	Tested on a realistic scale on selected walls and roofs in the Former Soviet Union and in Europe after the Chernobyl accident.		
Key references	Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315 Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p		
Version	2		
Document history	See Table 3.2.		

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14 High pressure hosing

Objective	To reduce external gamma and beta doses and inhalation doses from contamination on external walls and roofs of buildings within inhabited areas.
Other benefits	Will remove contamination from external building surfaces.
Management option description	Pressure-washing equipment can be used to loosen contamination from a surface and wash it off. A continuous water flow is applied at high pressure of about 150 bar (2000 psi). Washing must start at the top of walls and roofs and it is particularly important to avoid lifting roof tiles by forcing water upwards. A pump is mounted on the ground and hoses are fed to a platform or scaffolding. Use of high pressure jets at pressures significantly above 150 – 200 bar is not advisable on roofs as this may lead to lifting of the tiles. **Roofs:** it should be practicable to collect the water used for high pressure hosing. Collection of water from roofs can be aided by modifying guttering and drainpipes, so that the collected waste is fed into collection tanks, where it may be filtered (most of radioactivity will be associated with the solid phase). If no active means are adopted to collect the water, some of the waste water may soak into the ground and the rest will pass directly into the drains or to soak-aways via gutters and drainpipes. It may be necessary to apply a surface treatment to roofs to ensure protection against future water penetration. **Walls:** it is unlikely to be practicable to collect the waste water and associated contamination. **Ground:** The implementation of options to the surrounding ground surfaces should also be considered after high pressure hosing has been implemented, if run-off to ground surfaces has occurred. If the implementation of any other options to the surrounding ground surfaces is planned, high pressure hosing of walls and roofs should be implemented first.
Target	External walls and roofs of buildings (highly contaminated).
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides.
Scale of application	Any size building.
Time of application	Maximum benefit if carried out soon after deposition when maximum contamination is still on the surfaces. However, high pressure hosing of external walls and roofs of buildings can be effective up to 10 years after deposition.
Constraints	
Legal constraints	Liabilities for possible damage to property (e.g. flooding). Ownership and access to property. Disposal of contaminated water via public sewer system. Use on listed and other historical buildings.
Environmental constraints	Severe cold weather (water would need to be heated). Walls must be waterproof. Roof constructions must resist water at high pressure.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of between 1.5 and 5 can be achieved if it is implemented soon after deposition. A higher DF can be achieved following dry deposition rather than wet deposition. In the case of plutonium, a DF of between of 10 and 2 can be achieved. For elemental iodine and tritium, thorough hosing of impermeable surfaces will lead to virtually full removal of contamination. The effectiveness of high pressure hosing decreases with time elapsed since contamination occurred, especially in areas with high rainfall rates. Repeated application is unlikely to provide any significant increase in DF.
Reduction in surface dose rates	External gamma and beta dose rates from decontaminated external walls and roofs of buildings will be reduced by a factor similar to the DF.
Reduction in resuspension	Resuspended activity in air will be reduced by the value of the DF.
Technical factors influencing effectiveness	Water pressure. Type, evenness & condition of surface, including the amount of moss on roofs. Time of operation: the longer the time between deposition and implementation of the option the less effective it will be due to fixing of the contamination to the surface. Consistent application of water over the contaminated area (ie operator skill). Care in application: care needed to wash contamination from walls and roofs and not just move the contamination around the surface; lower part of walls need to be cleaned very carefully as this is the surface that will provide the greatest dose to an individual in the vicinity of the building; special care needed to clean roof gutters and drain pipes. Whether the ground surrounding the building and other surfaces onto which run-off may have occurred have been decontaminated after treating the building (if waste was not collected). Number of buildings in the area. Time of implementation: weathering will reduce contamination over time so quick

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14 High pressure hosing

<table>
<tr><td></td><td colspan="8">implementation will improve effectiveness.</td></tr>
<tr><td>Social factors influencing effectiveness</td><td colspan="8">Public acceptability of waste treatment and storage routes.</td></tr>
<tr><td colspan="9">Feasibility</td></tr>
<tr><td>Equipment</td><td colspan="8">The equipment used will depend on whether the waste water is filtered prior to disposal.
The equipment used for high pressure hosing can include:
2000 psi pressure washer
7.5kW generator
Filter
Spate pump
Gully sucker
Scaffolding with roof ladders for additional roof access
Transportation vehicles for equipment and waste</td></tr>
<tr><td>Utilities and infrastructure</td><td colspan="8">Roads for transport of equipment and waste.
Water supply.
Public sewer system.</td></tr>
<tr><td>Consumables</td><td colspan="8">Fuel and parts for generators and transport vehicles.
Surface treatment for roofs (if required).</td></tr>
<tr><td>Skills</td><td colspan="8">Skilled personnel essential to operate high pressure hoses and gully suckers.</td></tr>
<tr><td>Safety precautions</td><td colspan="8">For tall buildings: lifeline and safety helmets.
Water-resistant clothing should be recommended, particularly in highly contaminated areas.
Personal protective equipment (PPE) should be considered to protect workers from contaminated water spray.
Precautions are needed to ensure that people making connections to mains water supplies do not inadvertently contaminate the water supply, e.g. by back-flow from vessels containing radioactivity or other contaminants, or operate hydrants in a way that disturbs settled deposits within the water main system.</td></tr>
<tr><td colspan="9">Waste</td></tr>
<tr><td>Amount</td><td colspan="8">2 10^{-1} – 4 10^{-1} kg m^{-2} solid and 20 l m^{-2} water.</td></tr>
<tr><td>Type</td><td colspan="8">Dust and water.</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td rowspan="5">Averted dose</td><td colspan="4">Cs-137
(% reduction in external dose)</td><td colspan="4">Pu-239
(% reduction in resuspension dose)</td></tr>
<tr><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td><5</td><td><5</td><td><5</td><td><5</td><td>0</td><td><5</td><td><5</td><td><5</td></tr>
<tr><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area. The estimated dose reductions do not include any potential future doses that may arise if contaminated water enters the drainage system and subsequently the wider environment (see Appendix C for further information).</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Consistency in effective implementation of option over a large area
Care in application. Care needed to wash contamination from walls and roofs and not just move the contamination around the surface; lower part of walls need to be cleaned very carefully as this is the surface that will provide the greatest dose to an individual in the vicinity of the building; special care needed to clean roof gutters and drain pipes.
Whether the ground surrounding the building and other surfaces onto which run-off may have occurred have been decontaminated after treating the building (if waste was not collected).
Population behaviour in the area.
Number of buildings in the area, i.e. environment type/land use.
Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)
• inhalation of dust and water spray generated
• *inadvertent ingestion of dust from workers' hands*
Contributions from pathways in italics are will not be significant and doses from these</td></tr>
</table>

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14 High pressure hosing

	pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included. No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.	
Intervention costs		
Operator time	Work rate (m^2/team.hr)	30 – 60 (excludes setting up scaffolding, if required)
	Team size (people)	Up to 3 (depends on equipment used for access to buildings. More people needed if water is collected and filtered prior to disposal)
Factors influencing costs	Weather. Building size. Type of equipment used. Access. Proximity of water supplies. Use of personal protective equipment (PPE).	
Side effects		
Environmental impact	High pressure hosing will create contaminated waste water. However, this should be minimised through the control of any disposal route and relevant authorisations. If waste water is not collected, some of it will run onto other surfaces (roads, soil, grass etc), resulting in a transfer of contamination which may require subsequent clean-up, generating more waste. It is important that high pressure hosing of buildings is implemented before the implementation of any recovery options to surrounding ground surfaces.	
Social impact	Acceptability of active disposal of contaminated waste water into the public sewer system. High pressure hosing of buildings will make an area look clean; implementation may give public reassurance. Repair work on some walls and roofs may be required.	
Practical experience	Tested on realistic scale on selected walls and roofs in the Former Soviet Union and Europe after the Chernobyl accident.	
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, 46, (2), 207-223. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315 Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996*). Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. Roed J and Andersson KG (1996). Clean-up of urban areas in the CIS countries contaminated by Chernobyl fallout. *Journal of Environmental Radioactivity*, 33 (2), 107-116. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p.	
Version	2	
Document history	See Table 3.2.	

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15 Mechanical abrasion of wooden walls

Objective	To reduce external gamma and beta doses from contamination on external wooden walls of buildings within inhabited areas, and reduce inhalation dose from material resuspended from these surfaces.
Other benefits	Will remove contamination from external wooden walls of buildings.
Management option description	The contamination level on a (painted) wooden wall may be reduced by abrasion using an electric hand held drill. This grinding procedure, which is commonly used to clean surfaces prior to painting, removes a thin surface layer (a few mm) and the associated contamination. Fixing nails may need to be punched in or extracted before the operation. Resurfacing (e.g., painting) is generally required after the operation. This option is likely to give rise to dust, so application of water to dampen the surface or the use of a tie-down material (see data sheet 21) is recommended prior to implementation to limit the resuspension hazard. Recontamination of surface by resuspended contaminants will be insignificant, so repeated application is not required.
Target	Highly contaminated (painted) wooden external walls of buildings.
Targeted radionuclides	All long-lived beta and gamma emitting radionuclides. Should not be considered for removal of short-lived radionuclides alone. See Table 1.1 for information on radionuclides.
Scale of application	Any size. Suitable for small areas (e.g. houses) and large areas (e.g. industrial buildings/schools etc).
Time of application	Maximum benefit if carried out soon after deposition. Delay will allow horizontal migration of contaminants into wall, although this effect is unlikely to be significant on painted walls.
Constraints	
Legal constraints	Liability for possible damage to property. Ownership and access to property. Cultural heritage protection of listed and other historically important buildings.
Environmental constraints	Use on listed and historic buildings
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of between 1.5 and 2.5 can be achieved if this option is implemented soon after deposition. Repeated application is unlikely to provide any significant increase in DF.
Reduction in surface dose rates	External dose rates from external wooden walls of buildings will be reduced by approximately the same value as the DF.
Reduction in resuspension	Resuspended activity concentrations in air will be reduced by the same value as the DF.
Technical factors influencing effectiveness	Contaminant aerosol size (large particles may be more easily removed). The effectiveness of mechanical abrasion decreases with time after deposition, as the contamination may migrate horizontally deeper into the surface. This will depend on the permeability of the wall surface. Operator skills and degree of abrasion.
Social factors influencing effectiveness	None.
Feasibility	
Equipment	A powered sander. This could be a specialist piece of equipment or a hand-held drill mounted with sandpaper discs or steel wool for grinding (cost about € 100). Scaffolding or mobile lifts for tall buildings. Transport vehicles for equipment and materials.
Utilities and infrastructure	Power supply (petrol-driven mobile generator may be applied if power is not available).
Consumables	Steel wool or sandpaper to be mounted on the drill. Fuel and parts for generators, it required.
Skills	Only a little instruction is likely to be required.
Safety precautions	For tall buildings: lifeline and safety helmets. Respiratory protection is essential.
Waste	
Amount and type	About 0.1 kg m-2 solid waste, which it would be very difficult to collect. N.B. Some sanders have in-built dust collectors which perform to varying degrees of efficiency.
Doses	

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15 Mechanical abrasion of wooden walls

Averted dose	Reductions in external gamma dose rate shortly after decontamination of the walls of the building received by a member of the public living in an inhabited area could be expected to be around 5% following deposition under dry conditions. Following wet deposition, reductions in dose rates will be negligible. This is an illustrative value and should only be used to provide an indication of the likely effectiveness of this option and to compare across options.
Factors influencing averted dose	Effective and consistent application of option. The lower part of the wall needs to be cleaned carefully, as this is the surface that will provide the greatest dose to an individual near the building. Whether the surfaces surrounding the building have been decontaminated after treatment. Number of buildings in the area, i.e. environment type / land use. Population behaviour in area and the time spent by individuals close to or in wooden buildings.
Additional doses	Exposure pathways workers could be exposed to are: External exposure from environment and contaminated equipment Inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) Inadvertent ingestion of dust from workers' hands Contributions from pathways in italics will not be significant and using personal protective equipment (PPE) can control doses from these pathways. Exposure routes from transport and disposal of waste are not included. Beta/gamma hazard: For radionuclides that present a beta/gamma hazard, external dose to workers from contamination in the environment will be a few times higher than public doses over the period of implementation. Even under very dusty conditions, the inhalation dose from resuspended material will only make a small contribution to the total worker dose. Alpha hazard: For radionuclides that present an alpha hazard, inhalation dose to workers from resuspended material will typically be a few times higher than public doses over the period of implementation. External dose from contamination in the environment can be ignored.
Intervention costs	
Operator time	2 m^2/team.hr (team size: 1 person) Excludes time for setting up scaffolding, if required.
Factors influencing costs	The following are factors that will influence the time taken to implement the option and hence labour costs: Weather Building size Type of equipment used Access Use of personal protective equipment (PPE) Also, costs will increase if scaffolding is required, and if repainting of walls is required.
Side effects	
Environmental impact	None.
Social impact	Implementation will make an area look clean and thus aid public reassurance. Distribution of contaminated paint particles in the environment may be unacceptable.
Practical experience	Tested on a realistic scale on selected walls in the former Soviet Union after the Chernobyl accident.
Key references	Andersson KG, Roed J, Eged, K, *et al* (2003). Physical Countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas. Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). Strategies of decontamination. Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. Roed J, Andersson KG and Prip H (ed.) (1995). Practical Means for Decontamination 9 Years After a Nuclear Accident. Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82 p.
Version	2
Document history	See Table 3.2.

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16 Roof brushing

Objective	To reduce external gamma and beta doses and inhalation doses from contamination on roofs of buildings within inhabited areas.
Other benefits	Will remove contamination from roofs of buildings.
Management option description	The roof is cleaned using commercially available rotating brushes driven by compressed air. Cleaning is carried out in a closed (shielded) ‘box’ system. The device is mounted on an extendable rod that allows operation from the top of the roof or, in the case of single-storey buildings, from the ground. Contaminated waste can be segregated; water can be filtered and recycled. Waste is largely solids (e.g. moss) that are collected. Dust creation is unlikely to be a problem during implementation.
Target	Roofs of buildings.
Targeted radionuclides	All radionuclides. Short-lived radionuclides if implemented quickly.
Scale of application	Suitable for roofs of buildings.
Time of application	Maximum benefit if carried out soon after deposition. But can be effective up to 10 years after deposition depending on roof material and level of removable debris on the roof.
Constraints	
Legal constraints	Liabilities for possible damage to property. Use on listed and other important buildings. Ownership and access to property. Solid waste disposal.
Environmental constraints	Severe cold weather (may require heating of water).
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of between 2 and 7 can be achieved. Repeated application is unlikely to provide any significant increase in DF. In the short term, the quoted DF range can be considered to be the same for all radionuclides, with the exception of elemental iodine and tritium for which thorough washing of impermeable surfaces will lead to virtually full removal.
Reduction in surface dose rates	External gamma and beta dose rate contributions from roofs of buildings will be reduced by approximately the value of the DF.
Reduction in resuspension	Resuspended activity in air above the roof surface can also be assumed to be reduced by the value of the DF.
Technical factors influencing effectiveness	Roof material. Amount of removable debris on roof, e.g. moss, pine needles. Consistency in effective implementation of option over entire area. Careful implementation: special care must be taken to clean roof gutters and drain pipes. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Number of buildings in the area.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Pressure washer with rotating brush attachment, filters & collection tank. Scaffolding and roof-ladders or fire-tender with hydraulic platform. Transportation vehicles for equipment and waste.
Utilities and infrastructure	Roads for transport of equipment and waste. Water supply.
Consumables	Water. Fuel for generators and transport vehicles.
Skills	Skilled personnel essential for working at heights.
Safety precautions	Lifeline. Safety helmets. Water-proof clothing should be recommended. Precautions are needed to ensure that people making connections to mains water supplies do not inadvertently contaminate the water supply, e.g. by back-flow from vessels containing radioactivity or other contaminants, or operate hydrants in a way that disturbs settled deposits within the water main system.
Waste	
Amount and type	*Amount:* $2\ 10^{-1} – 6\ 10^{-1}$ kg m^{-2} solid and 15 l m^{-2} water. *Type:* Dust and moss (sludge). Amount of waste depends on amount of moss and other debris on the roof. Care must be

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16 Roof brushing

<table>
<tr><td></td><td colspan="8">taken not to block drains with moss etc.
Water can be filtered and recycled.</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td rowspan="5">Averted dose</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239 (% reduction in resuspension dose)</td></tr>
<tr><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td><5</td><td>10-15</td><td><5</td><td><5</td><td>0</td><td><5</td><td><5</td><td><5</td></tr>
<tr><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Consistency in effective implementation of option over entire area Careful implementation. Special care must be taken to clean roof gutters and drain pipes. Care should be taken to wash contamination to the roof gutter and not just move it around the roof.
Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Population behaviour in area.
Amount of buildings in the area ie environment type/land use.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)
• inhalation of dust generated
• *inadvertent ingestion of dust from workers' hands*
Contributions from pathways in italics will not be significant and doses from these pathways can be controlled by using PPE.
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td>Operator time</td><td colspan="8">8 m^2/team.hr (team size: 1 - 2 people).
Work rate excludes setting up scaffolding.</td></tr>
<tr><td>Factors influencing costs</td><td colspan="8">Weather.
Building height and pitch of roof.
Type of equipment used.
Access.
Proximity of water supplies.
Type of surface, numbers of gutters etc.</td></tr>
<tr><td colspan="9">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="8">The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.</td></tr>
<tr><td>Social impact</td><td colspan="8">Brushing of roofs will make an area look clean; implementation may give public reassurance.
Damage may be caused to roofs by brushing.</td></tr>
<tr><td>Practical experience</td><td colspan="8">Tested on realistic scale on selected roofs of different types in the Former Soviet Union after the Chernobyl accident.</td></tr>
<tr><td>Key references</td><td colspan="8">Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2.
Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark.
Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315
Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR
Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996*). Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3.
Roed J and Andersson KG (1996). Clean-up of urban areas in the CIS countries contaminated by Chernobyl fallout. *Journal of Environmental Radioactivity*, 33 (2), 107-116.
Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840,</td></tr>
</table>

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	82p. Roed J, Lange C, Andersson KG, Prip H, Olsen S, Ramzaev VP, Ponomarjov AV, Varkovsky AN, Mishine AS, Vorobiev BF, Chesnokov AV, Potapov VN and Shcherbak SB (1996). *Decontamination in a Russian settlement.* Risø National Laboratory, Risø-R-870, ISBN 87-550-2152-2.
Version	2
Document history	See Table 3.2.

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17 Roof cleaning with pressurised hot water

Objective	To reduce external gamma and beta doses and inhalation doses from contamination on roofs of buildings within inhabited areas.
Other benefits	Will remove contamination from roof surfaces.
Management option description	Rotating nozzles are driven by hot water at high pressure. Cleaning is performed in a closed (shielded) 'box' system. The device is mounted on a trolley that can be drawn across the roof. It is operated from the top of the roof, lowered down the roof using the pressure water hose. It should be noted that the use of hotter water (ca. 80 °C) and detergent can considerably increase the effectiveness of the procedure. Care must be taken not to block drains with moss, etc. Waste water can be easily collected via downpipes. However, water may be allowed to pass into drains or to soak-aways via gutters and drainpipes. Cleaning of these should be considered after implementation. The implementation of options to the surrounding ground surfaces should also be considered following roof cleaning if contaminated water drained onto the ground surrounding the buildings. If the implementation of any other options to the surrounding ground surfaces is planned, roof cleaning should be implemented first.
Target	Contaminated roofs of buildings, both residential and industrial.
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides.
Scale of application	Any size building
Time of application	Maximum benefit if carried out soon after deposition when maximum contamination is still on the surfaces. However roof cleaning can be effective up to 10 years after deposition depending on the roof material and removable debris/growth.
Constraints	
Legal constraints	Ownership and access to property Disposal of contaminated water via the public sewer system, if required Use on listed or other historical buildings
Environmental / technical constraints	Extreme cold weather Roof construction must resist water at high pressure.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of between 2 and 7 can be achieved if this option is implemented soon after deposition. In the short term, the quoted DF can be considered to be same for all radionuclides, with the exception of elemental iodine and tritium, for which thorough washing of impermeable surfaces will lead to virtually full removal. Even after 10 years, a DF of 2 – 4 can be achieved. The DF will be lowest for slate, clay and concrete roofs, and highest for silicon-treated slate, and possibly even higher for aluminium/ iron. If a surface layer of moss/algae covers the roof at the time of deposition, almost all the contamination may be removable.
Reduction in surface dose rates	External gamma and beta dose rates above decontaminated roofs of buildings will be reduced by approximately the value of the DF.
Reduction in resuspension	N/A
Technical factors influencing effectiveness	Material from which roof is constructed Evenness, condition of the surface Amount of moss/debris on roof Time of operation: the longer the time between deposition and implementation of the option the less effective it will be due to fixing of the contamination to the surface Water pressure, amount of water, water temperature (hotter water is more effective), use of detergent. Care taken to wash contamination to the roof gutter and not just transfer it onto other parts of the roof. Special care must be taken to clean roof gutters and drain pipes thoroughly after implementation. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes
Feasibility	
Equipment	Roof cleaning trolley High pressure hot water generator Scaffolds or mobile lifts for operation from the roof.

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17 Roof cleaning with pressurised hot water

	Transport vehicles for equipment (and waste)
Utilities and infrastructure	Water supply Public sewer system Roads for transporting equipment (and waste)
Consumables	Power supply Fuel and parts for generators if required (8 l h^{-1}) and transport vehicles Water (about 30 l m^{-2})
Skills	Can be carried out with little instruction - one person on the rooftop and one on the ground administrating supplies. Professionals are required for work on the roof.
Safety precautions	For tall buildings: lifeline and safety helmet. Water resistant clothing should be recommended, particularly in highly contaminated areas. Precautions are needed to ensure that people making connections to mains water supplies do not inadvertently contaminate the water supply, e.g. by back-flow from vessels containing radioactivity or other contaminants, or operate hydrants in a way that disturbs settled deposits within the water main system.
Waste	
Amount and type	Generates some 30 l m^{-2} of liquid waste, with approx 0.2 kg m^{-2} of solid waste containing nearly all the contamination. Waste may be toxic (asbestos). Water can be collected via the down-pipes and filtered using a simple filter prior to disposal via the drains or can be recycled.
Doses	
Averted doses	Reductions in external gamma dose rate shortly after decontamination of the roof surface received by a member of the public living in an inhabited area could be expected to be around 7 - 8 %. This is an illustrative value and should only be used to provide an indication of the likely effectiveness of this option and to compare across options. The estimated dose reductions do not include any potential future doses that may arise if contaminated water enters the drainage system and subsequently the wider environment (see Appendix C for further information).
Factors influencing averted dose	Consistency in effective implementation of the option over a large area Whether the ground surfaces below the roof (onto which run-off may have occurred) have been decontaminated after treating the roof (especially if there is no gutter and waste water is not collected). Number of buildings in the area, i.e. environment type / land use. Time spent by individuals close to buildings. Industrial buildings often have shallow sloping roofs resulting in high contamination levels and high dose rates.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) Exposure routes from transport and disposal of waste are not included.
Intervention costs	
Operator time	3 m^2 per team hour (team size: 2 people) Work rate excludes setting up scaffolding.
Factors influencing costs	Weather. Building size: size of scaffolds / mobile lifts. Roof gradient and amount of debris on roof. Access. Proximity of water supplies. Operator skill.
Side effects	
Environmental impact	Roof cleaning will create contaminated waste water. However, this should be minimised through the control of any disposal route and relevant authorisations. If waste water is not collected, some of it will run onto other surfaces (roads, soil, grass etc). These may require subsequent clean-up, generating more waste.
Social impact	Acceptability of active disposal of contaminated waste water into the public sewer system. Cleaning roofs will make buildings look cleaner; implementation may give public reassurance. Repair work on roof etc may be required but this is unlikely.
Practical experience	Tested on realistic scale on selected roofs of different types in the Former Soviet Union after

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17 Roof cleaning with pressurised hot water

	the Chernobyl accident.
Key references	Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark.
Version	2
Document history	See Table 3.2.

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18 Roof Replacement

Objective	To reduce external gamma and beta doses and inhalation doses from contamination on roofs of buildings within inhabited areas.
Other benefits	Will remove contamination from roofs together with old roof material.
Management option description	The contaminated roof covering is replaced with new or cleaned slates/tiles. Gutters and drainpipes also need to be removed. This option is likely to give rise to dust, so application of water to dampen the surface or the use of a tie-down material (see Datasheet 20) is recommended prior to implementation to limit the resuspension hazard. Careful checks will need to be made for asbestos before roof materials are removed.
Target	Highly contaminated roofs of residential and industrial buildings. This option is expensive and labour intensive and should only be considered if other options are not appropriate for the level of contamination.
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides alone.
Scale of application	Any size building.
Time of application	Maximum benefit if carried out soon after deposition while maximum contamination remains on the roof. Can still be effective up to 10 years after deposition depending on the roof material and removable debris on the roof. Also leaves and pine needles may continue to re-contaminate the roof over time.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use on listed or historic buildings.
Environmental constraints	High winds and wet weather may make implementation of this countermeasure difficult because of the danger to workers.
Effectiveness	
Reduction in contamination on the surface	All contamination from the roof should be removed. However, depending on the nature of the roofing material, a fraction of the contamination (usually small) may have penetrated into underlying wooden construction materials.
Reduction in surface dose rates	
Reduction in resuspension	Resuspended activity in air above the roof surface can be assumed to be reduced to zero.
Technical factors influencing effectiveness	Type of roof material. Time of application (material may permeate into underlying rafters). Consistency in effective implementation of option over an entire area. Thorough implementation of removal including gutters and drainpipes. Number of buildings in the area. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Depending on the type of roof-surface that is to be applied, hammers, cutters, and tools for extracting nails may be needed. Plastic sheets to protect the building interior from rain while the work is being carried out. Scaffolds or mobile lifts. Transport vehicles for equipment, materials and waste.
Utilities and infrastructure	Roads for transport of equipment, materials and waste.
Consumables	New roofing materials (e.g. tiles, slates and roofing felt). Fuel and parts for transport vehicles.
Skills	Skilled personnel essential for changing roofs.
Safety precautions	Lifeline. Safety helmets. Safety boots. Respiratory protection may be required if the process generates dust. Appropriate safety measures and respiratory protection will be required if asbestos is present.
Waste	
Amount and type	*Amount:* 2 10^{1} – 5 10^{1} kg m^{-2} (depending on type of roof and material). *Type:* tiles, slates, roofing felt etc.
Doses	
Averted doses	Shortly after replacement of the roof surface, reductions of approx. 9 – 11 % in external gamma dose rate received by a member of the public living in an inhabited area could be

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18 Roof Replacement

	expected. Figure 1.4 gives some indication of the likely importance of roofs in contributing to long term external gamma doses.
Factors influencing averted dose	Consistency in effective implementation of option over an entire area. Population behaviour in area. Number of buildings in the area i.e. environment type/land use. Whether the ground surfaces below the roof (onto which run-off may have occurred) have been decontaminated after replacing the roof. Time spent by individuals close to buildings. Industrial buildings often have shallow sloping roofs resulting in high contamination levels and high dose rates
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) • inhalation of dust generated • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included.
Intervention costs	
Operator time	1 – 3 m^2/team.hr (team size: 2 people) - depending on type of roof and material (excludes setting up of scaffolding).
Factors influencing costs	Weather. Building height. Type of equipment used. Access. Type of roof material. Use of personal protective equipment (PPE). Use of scaffolding.
Side effects	
Environmental impact	Disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations. The large quantity of waste produced may lead to this option not being feasible if implemented on anything more than a small scale.
Social impact	Acceptability of disposal of large amounts of contaminated waste. Damage may be caused to buildings by changing the roof. Positive impact on roofing industry.
Practical experience	Tested on a realistic scale on selected roofs of different types in the Former Soviet Union after the Chernobyl accident.
Key references	Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). *Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. Morgan CJ (1987). Methods and cost of decontamination and site restoration following dispersion of plutonium in a weapon accident. Aldermaston, AWE, SCT Laboratory. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p Roed J, Lange C, Andersson KG, Prip H, Olsen S, Ramzaev VP, Ponomarjov AV, Varkovsky AN, Mishine AS, Vorobiev BF, Chesnokov AV, Potapov VN and Shcherbak SB (1996). *Decontamination in a Russian settlement.* Risø National Laboratory, Risø-R-870, ISBN 87-550-2152-2.
Version	2
Document history	See Table 3.2.

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19 Sandblasting

Objective	To reduce external gamma and beta doses and inhalation doses from contamination on external walls of buildings within inhabited areas.
Other benefits	Will remove contamination from external building surfaces.
Management option description	Sandblasting of walls will remove a thin layer, together with the contamination. To eliminate the risk of contamination translocation on the wall, the sandblasting must begin at the top. Wet sandblasting is recommended (although dry sandblasting is generally almost as efficient, the resuspension of contaminants is difficult to control). Sand is injected into a high pressure water system and sprayed onto the surface, reached by scaffolding or fire-tender. A pump is mounted on the ground and hoses are fed to the platform or scaffolding. It is unlikely that it will be practicable to collect the water used for sandblasting. Some of the waste water will soak into the ground or pass into the drains. Dust creation during implementation is unlikely to be a problem and so methods are not required to reduce the resuspension hazard to workers. Workers should be protected from water spray. If walls are sufficiently contaminated to require treatment, the ground surfaces surrounding the building will almost certainly also be strongly contaminated and the consideration of recovery options for these surfaces is also recommended. If the implementation of any other options to the surrounding ground surfaces is planned, sandblasting of walls should be implemented first.
Target	Highly contaminated external walls of buildings.
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides alone.
Scale of application	Any size building.
Time of application	Maximum benefit if carried out soon after deposition. However, sandblasting of external walls of buildings can be effective up to 10 years after deposition.
Constraints	
Legal constraints	Liabilities for possible damage to property (e.g. flooding). Ownership and access to property. Waste disposal legislation. Use on listed and other historically important buildings.
Environmental / technical constraints	Severe cold weather (water may need to be heated). Walls must be waterproof if wet sandblasting is used.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of between 4 and 10 could be achieved if implemented soon after deposition. Effectiveness may decrease with time after deposition as the contamination penetrates deeper into the material and becomes harder to remove. Repeated application is unlikely to provide any significant increase in DF.
Reduction in surface dose rates	External gamma and beta dose rates from decontaminated external walls of buildings will be reduced by a similar factor as the DF.
Reduction in resuspension	Resuspended activity in air will be reduced by the same value as the DF.
Technical factors influencing effectiveness	Water pressure. Type of sand applied. Type, evenness and condition of surface. Consistent application of water and sand over contaminated area (ie operator skill). Care in application: care needed to wash contamination from walls and not just move the contamination around the surface. Lower part of walls need to be cleaned very carefully as this is the surface that will provide the greatest dose to an individual in the vicinity of the building. Number of buildings in the area i.e. environment type/land use. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes
Feasibility	
Equipment	Depends on whether the waste water is filtered prior to disposal. The equipment used for sandblasting can include: 150 bar (2000 psi) pressure washer Dry abrasive feeder Generator Sheeting Tanks

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19 Sandblasting

<table>
<tr><td></td><td colspan="8">Troughs
Filters
Spate pump
Gully sucker
Scaffolding with roof ladders for additional roof access
Transport vehicles</td></tr>
<tr><td>Utilities and infrastructure</td><td colspan="8">Roads (transport of equipment, materials and waste).
Water supply.
Public sewer system.</td></tr>
<tr><td>Consumables</td><td colspan="8">Water supply.
Sand.
Fuel and parts for generators and transport vehicles.</td></tr>
<tr><td>Skills</td><td colspan="8">Skilled personnel essential to operate sandblasting equipment.</td></tr>
<tr><td>Safety precautions</td><td colspan="8">For tall buildings: lifeline and safety helmets.
Water-resistant clothing and safety glasses should be recommended, particularly in highly contaminated areas.
Personal protective equipment (PPE) should be considered to protect workers against water spray.
Precautions are needed to ensure that people making connections to mains water supplies do not inadvertently contaminate the water supply, e.g. by back-flow from vessels containing radioactivity or other contaminants, or operate hydrants in a way that disturbs settled deposits within the water main system.</td></tr>
<tr><td colspan="9">Waste</td></tr>
<tr><td>Amount and type</td><td colspan="8">*Amount:* 3 kg m^{-2} solid and 50 l m^{-2} water.
Type: Dust, sand and water.</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td rowspan="5">Averted doses</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239 (% reduction in resuspension dose)</td></tr>
<tr><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td>5-10</td><td><5</td><td>5-10</td><td><5</td><td>0</td><td><5</td><td><5</td><td><5</td></tr>
<tr><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area. The estimated dose reductions do not include any potential future doses that may arise if contaminated water enters the drainage system and subsequently the wider environment (see Appendix C for further information).</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">• Consistency in effective implementation of option over a large area.
• Care in application. Care needed to wash contamination from walls and not just move the contamination around the surface. Lower part of walls need to be cleaned very carefully as this is the surface that will provide the greatest dose to an individual in the vicinity of the building.
• Whether the ground surrounding the building and other surfaces onto which run-off may have occurred have been decontaminated after treating the building (if waste was not collected).
• Population behaviour in the area.
• Amount of buildings in the area ie environment type/land use.
• Time after implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)
• inhalation of dust and water spray generated
• *inadvertent ingestion of dust from workers' hands*
Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE.
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td rowspan="2">Operator time</td><td colspan="3">Work rate (m^2/team hr)</td><td colspan="5">15 – 20 (excludes setting up scaffolding)</td></tr>
<tr><td colspan="3">Team size (people)</td><td colspan="5">3 – 6 (depends on equipment used for access to buildings and whether waste water is collected)</td></tr>
<tr><td>Factors influencing costs</td><td colspan="8">Weather.</td></tr>
</table>

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19 Sandblasting

	Building size. Type of equipment used. Access. Proximity of water supplies. Use of personal protective equipment (PPE).
Side effects	
Environmental impact	Sandblasting will create contaminated waste water so appropriate monitoring will be required in the sewage treatment plant. The disposal or storage of waste arising from this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations. If waste water is not collected, some of it will run onto other surfaces (roads, soil, grass etc), resulting in a transfer of contamination which may require subsequent clean-up, generating more waste.
Social impact	Acceptability of active disposal of contaminated waste water into the public sewer system. Sandblasting of buildings will make an area look clean; implementation may give public reassurance. Repair work on some walls may be required.
Practical experience	Tested on realistic scale on selected walls in the Former Soviet Union and Europe after the Chernobyl accident.
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315 Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996*). Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. Roed J and Andersson KG (1996). Clean-up of urban areas in the CIS countries contaminated by Chernobyl fallout. *Journal of Environmental Radioactivity*, **33** (2), 107-116. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p
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Document history	See Table 3.2.

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20 Tie-down (fixing contamination to the surface)

Objective	To reduce inhalation doses from material resuspended from external building surfaces within inhabited areas in the short or long term.	
Other benefits	May also reduce external beta doses.	
Management option description	Acrylic paint (e.g. Vinacryl) is sprayed onto the surface by spray injection. Likely to be only used prior to implementation of other recovery options in order to protect workers from the resuspension hazard.	
Target	External walls and roofs of buildings.	
Targeted radionuclides	Alpha emitting radionuclides. May be used for other radionuclides if conditions mean that inhalation doses from resuspended material are likely to be of concern.	
Scale of application	Any size building.	
Time of application	Maximum benefit if carried out soon after deposition but may be used at any time after deposition. Tie-down is effective for the period over which the integrity of the covering is maintained.	
Constraints		
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use on listed and other historic buildings.	
Environmental constraints	Severe cold weather.	
Effectiveness		
Reduction in contamination on the surface	It is assumed that the decontamination factor (DF) is 1. If subsequently removed, some contamination may be removed along with the tie-down material.	
Reduction in surface dose rates	While the tie-down material is in place, external beta dose rates adjacent to the surface will be reduced by a factor depending on the energy of the beta emissions; this option will be more effective at reducing dose rates associated with low energy beta emissions. It is not effective at reducing external gamma dose rates adjacent to the surface.	
Reduction in resuspension	While the tie-down material is in place, resuspended activity in air adjacent to the surface will be reduced by close to 100 %.	
Technical factors influencing effectiveness	Weather. Correct and consistent application of tie-down material over the contaminated area. Type and condition of surface. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Length of time tie-down material is in place.	
Social factors influencing effectiveness	None	
Feasibility		
Equipment	Airless spray pump and compressor. Access by scaffolding or fire-tender with hydraulic platform. Transport vehicles for equipment are required.	
Utilities and infrastructure	Roads for transport of equipment, materials and waste.	
Consumables	Acrylic paint (e.g. Vinacryl). Fuel and parts for transport vehicles.	
Skills	Skilled personnel essential to operate equipment.	
Safety precautions	Gloves and overalls.	
Waste		
Amount and type	If paint is subsequently removed: amount - 4 10^{-1} kg m^{-2}; type – paint.	
Doses		
Averted doses	Not estimated.	
Factors influencing averted dose	Consistency in effective implementation of option over a large area. Population behaviour in the area. Number of buildings in the area. Length of time tie-down material is in place.	
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) Exposure routes from transport and disposal of waste are not included.	
Intervention costs		
Operator time	Work rate (m^2/team hr)	1.5 10^2 – 2 10^2 (excludes setting up of scaffolding)

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20 Tie-down (fixing contamination to the surface)

	Team size (people)	3 – 6 (depends on size of area, equipment used and access to surfaces)
Factors influencing costs	Weather. Height of building. Size of area. Type of equipment used. Access.	
Side effects		
Environmental impact	If paint is later removed, the disposal or storage of waste may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.	
Social impact	Acceptability of contamination remaining in-situ. Acceptability of potential future doses to those maintaining external building surfaces.	
Practical experience	None	
Key references	Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315 Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR	
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21 Treatment of walls with ammonium nitrate

Objective	To reduce external dose from caesium contamination on external walls of buildings in inhabited areas.
Other benefits	Will reduce caesium contamination on external walls of buildings.
Management option description	An ammonium nitrate solution in water (0.1 M) is sprayed on the target wall at low pressure using a pump and hose. The ammonium ion exchanges with caesium ions, reducing the wall contamination. A continuous water flow should be applied on the wall to transport contamination to the ground. The washing must start at the top of the wall which must subsequently be washed with clean water to minimise corrosion. The ground surface below the wall should ideally be treated afterwards. Workers may need to be protected against water/chemical spray. The use of chemicals may cause an environmental hazard.
Target	Highly contaminated external walls of buildings.
Targeted radionuclides	Caesium.
Scale of application	Suitable for small and large areas.
Time of application	Maximum benefit if carried out soon after deposition when maximum contamination is still on the surfaces and before rain can wash contamination onto adjacent surfaces.
Constraints	
Legal constraints	Liability for possible damage to property. Ownership and access to property. Restrictions on chemical use. Cultural heritage protection of listed and other historically important buildings.
Environmental constraints	Extreme cold weather (solution needs to be heated). Walls must be water resistant.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of between 1.5 and 2 can be achieved if the option is implemented soon after deposition. Repeated application is unlikely to provide any significant increase in DF. Up to a few years after deposition, DF values of up to 1.5 could still be expected.
Reduction in surface dose rates	External gamma and beta dose rates from walls of buildings will be reduced by approximately the value of the DF.
Reduction in resuspension	N/A
Technical factors influencing effectiveness	Spraying time. Contaminant aerosol type (chemical form of caesium). Permeability of surface (walls must be water resistant). Care taken to wash contamination to the ground and not just transfer it onto the wall. The bottom part of the wall should be cleaned particularly well, as this is closest to any persons outside and close to the building. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Water hose and pump. Transport vehicles for equipment. Scaffolding or mobile lifts for tall buildings.
Utilities and infrastructure	Water supply: could be a problem in periods of drought. Power supply. Fuel and parts for transport vehicles.
Consumables	Ammonium nitrate. Water.
Skills	Only a little instruction required. The method is not recommended for self-help as ammonium nitrate is a highly reactive chemical.
Safety precautions	For tall buildings: lifeline, safety helmets. Normal safety procedures for handling chemicals. Water-proof safety clothing recommended, particularly in highly contaminated areas. Respiratory protection may be considered to protect workers from contaminated water spray if conditions are windy.
Waste	
Amount and type	Approx. 6 l m^{-2} of liquid waste. Waste water is impossible to collect.

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21 Treatment of walls with ammonium nitrate

Doses	
Averted doses	**Dry conditions**: reductions of approx. 4 % in external dose rate received by a member of the public living in an inhabited area could be expected shortly after treatment of the building surfaces. **Wet conditions**: reductions in dose rates will be negligible.
Factors influencing averted dose	Consistency in carrying out the procedure over a large area. Whether the surfaces surrounding the building are decontaminated after treating the building. Number of buildings in the area, i.e. environment type / land use. Population behaviour in the area and time spent by individuals close to or inside buildings.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) Exposure routes from transport and disposal of waste are not included.
Intervention costs	
Operator time	12 m^2 per team hour (team size 1 person). Work rate excludes variable time for setting up scaffolding/transport.
Factors influencing costs	Weather. Building size. Access. Proximity of water supplies. Use of personal protective equipment (PPE). Note: costs will increase if scaffolding is required, and if repainting of walls is required.
Side effects	
Environmental impact	Contaminated waste water from ammonium treatment will run onto other surfaces (roads, soil, grass etc), resulting in a transfer of contamination which may require subsequent clean-up, generating more waste. Ammonium nitrate may reach the ground water. Ammonium nitrate can corrode steel surfaces.
Social impact	Aesthetic consequences of changes of colour of building surfaces e.g. colour change on painted metal surfaces.
Practical experience	Tested on realistic scale on selected walls in the Former Soviet Union and Europe, after the Chernobyl accident.
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). *Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. Roed J and Andersson KG (1996). Clean-up of urban areas in the CIS countries contaminated by Chernobyl fallout. *Journal of Environmental Radioactivity*, **33** (2), 107-116. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p. Sandalls FJ (1987). Removal of radiocaesium from urban surfaces. *Radiation Protection Dosimetry*, **21**, (1/3), 137-140.
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Document history	See Table 3.2.

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22 Aggressive cleaning of indoor contaminated surfaces

Objective	To reduce inhalation and external gamma and beta doses arising from contamination on indoor floor and wall surfaces of large public buildings (e.g. railway stations) within inhabited areas.
Other benefits	Removal of contamination from indoor floor & wall surfaces in buildings.
Management option description	The techniques likely to be considered are high pressure hosing, sandblasting and surface removal. For high pressure hosing (and sandblasting), water at 2000 psi is pumped through a hand-held nozzle. All machines have the capability of introducing detergent, other chemicals or grit into hot or cold water. For large areas such as railway stations, 5000 psi pumped water could be used with equipment mounted on a heavy trolley. The water is pressurised by a trailer mounted pump with water supplies from tanks, hydrants or fire tenders. For large areas with outside access, gully suckers could be used to collect the waste water. Segregation of contaminated waste may be possible by filtration of the aqueous waste. Clean-up of the surrounding ground/other surfaces or the implementation of other appropriate options should be considered if waste water is not collected.
Target	Indoor surfaces of buildings robust enough to withstand invasive cleaning/removal.
Targeted radionuclides	All radionuclides. Not short-lived radionuclides alone.
Scale of application	Large areas of indoor surfaces in public buildings, particularly those open to the outdoors, e.g. railway stations.
Time of application	Maximum benefit if carried out soon after deposition when maximum contamination is still on surfaces. However, these techniques may be effective up to several years after deposition, although this will depend on the cleaning and weathering that has taken place prior to clean-up.
Constraints	
Legal constraints	Liabilities for possible damage to property (e.g. flooding). Ownership and access to property. Disposal of contaminated water via public sewer system. Use on listed sites, historical buildings or in conservation areas.
Environmental constraints	Surfaces must be waterproof and resist water at high pressure. Nearby drains are required if water is not to be collected
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of up to 10 could be expected for high pressure hosing and sandblasting of concrete, stone and brick surfaces (floors and walls) if this option is implemented within a few weeks of deposition and no previous cleaning has taken place. For smooth surfaces, such as tiles, linoleum, and glass, a higher DF could be expected. Repeated application is unlikely to provide any significant increase in DF if implemented thoroughly the first time.
Reduction in surface dose rates	External gamma and beta dose rates immediately above cleaned surfaces will be reduced by a factor similar to the DF.
Reduction in resuspension	A reduction in resuspension from the cleaned surfaces could be expected to be of the same value as the DF.
Technical factors influencing effectiveness	Type and condition of surface. Type of method applied. Time of operation (contaminated dust migrates over time). Amount of dust on surfaces at the time of deposition. Whether any cleaning has already been undertaken Efficiency of equipment and water pressure used. Weather at time of deposition; less material is deposited indoors during wet deposition.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	(Depends on whether waste water is filtered prior to disposal.) 2000 psi pressure washer. 7.5 kW generator. Filter. Spate pump. Gully sucker with fishtail attachment. Transport vehicles for equipment and waste. Pneumatic hammers.
Utilities and infrastructure	Roads for transport of equipment and waste.

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22 Aggressive cleaning of indoor contaminated surfaces

	Water and power supplies. Public sewer system.	
Consumables	Water. Fuel and parts for generators and transport vehicles. Sand/grit for sandblasting.	
Skills	Skilled personnel essential to operate machinery.	
Safety precautions	Water resistant clothing should be recommended, particularly in highly contaminated areas Personal protective equipment (PPE), including respiratory protection, should be considered to protect workers from contaminated water spray.	
Waste		
Amount and type	Variable depending on technique and whether water is collected. Sandblasting: 3 kg m^{-2} of solid waste (dust + filters) + water used.	
Doses		
Averted doses	Some indication of possible dose reductions can be found in Datasheet 14 (high pressure hosing building exteriors), and Datasheet 19 (sandblasting building exteriors). However, it should be noted that these techniques will only reduce doses to people while they are indoors and averted doses will be dependent on specific situations and the surfaces cleaned.	
Factors influencing averted dose	Consistent application over the contaminated area. Appropriate clean-up to other indoor surfaces and objects. Amount of time spent inside buildings.	
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the floor and other surfaces (may be enhanced over normal levels) Exposure routes from transport and disposal of waste are not included.	
Intervention costs		
Operator time	Work rate (m^2/team hr)	1 10^2 for high pressure hosing and sandblasting
	Team size (people)	1-2 people for high pressure hosing/sandblasting. If water is collected, more people will be required.
Factors influencing costs	Weather. Type of equipment used. Access. Proximity of water supplies. Use of personal protective equipment (PPE).	
Side effects		
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.	
Social impact	Acceptability of active disposal of contaminated waste water into the public sewer system. Cleaning will make an area look clean. Repair work to some surfaces may be required.	
Practical experience	None.	
Key references	Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR.	
Version	2	
Document history	See Table 3.2. Datasheet developed from separate datasheets for building indoor surfaces in UK Handbook 2005 called 'High Pressure Hosing', 'Sandblasting' and 'Scabbling' in EURANOS handbook 2007 and later.	

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23 Other cleaning methods (scrubbing, shampoo, steam cleaning)

Objective	To reduce inhalation and external gamma and beta doses arising from contamination on internal surfaces of buildings and indoor objects within inhabited areas.
Other benefits	Will remove contamination from indoor surfaces and objects in buildings.
Management option description	A variety of cleaning methods are available (e.g. scrubbing, shampooing, steam cleaning). The method chosen will be dependent on the target surfaces and the materials. Scrubbing wood may be inadvisable as contaminated water is forced between cracks, contaminating the surface below. During shampoo/steam cleaning, machines spray hot or cold detergent solution onto upholstered surfaces, carpets, tapestries etc, and it is vacuumed off before the fabric becomes saturated. Contaminated waste that is produced may be collected.
Target	Indoor surfaces of residential and other buildings and household objects that are robust enough to be cleaned with water.
Targeted radionuclides	All radionuclides. Suitable for removing short-lived radionuclides if implemented quickly.
Scale of application	Indoor surfaces in all types of buildings.
Time of application	Maximum benefit if carried out within a few weeks of deposition when maximum contamination is on surfaces.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use in listed or other historic buildings and on precious objects.
Environmental constraints	Steam cleaners, which use very hot water, are not suitable for all surfaces. The use of chemicals may cause an environmental hazard.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of 5 can be achieved for carpets, rugs, tapestries, upholstery, bedding and soft furnishings can be achieved if this option is implemented within a few weeks of deposition and no previous cleaning has taken place. However, the variation in DF is likely to be large. The highest DFs can be expected by cleaning smooth surfaces such as wood, tiles, linoleum, Marley tiles, glass and papered and painted walls. Decontamination factors are likely to be much lower for cleaning rough surfaces such as concrete, stone and brick surfaces (floors, walls, ceilings) and for carpets, rugs, tapestries, upholstery, bedding and soft furnishings. Reductions in external doses received by a member of public living in the area will depend on the amount of time spent by individuals inside the buildings (see below). Repeated application is unlikely to provide any significant increase in DF if implemented thoroughly the first time.
Reduction in surface dose rates	External gamma and beta dose rates directly above surfaces will be reduced by a factor similar to the DF.
Reduction in resuspension	Resuspended activity in air will be reduced by a value similar to the DF.
Technical factors influencing effectiveness	Type and condition of surface. Type of cleaning method used. Time of operation (the longer the time between deposition and implementation of the option the less effective it will be as contaminated dust may have migrated over time). Size and chemical reactivity of contaminant particles. Amount of dust on surfaces at the time of deposition. Whether any cleaning has already been undertaken. Efficiency of equipment. Weather at time of deposition; less material is deposited indoors during wet deposition. Appropriate clean-up of other indoor surfaces and objects. Ability to clean surfaces and objects thoroughly.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Scrubbing machines with solution dispenser. Steam cleaners. Spray machines. Wet vacuum cleaners. Transport vehicles for equipment and waste.
Utilities and infrastructure	Electricity supply.

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23 Other cleaning methods (scrubbing, shampoo, steam cleaning)

	Water supply. Roads for transport of equipment and waste.	
Consumables	Fuel and parts for vehicles. Water and detergent.	
Skills	Only a little instruction is likely to be required. However, it is important that the specific objectives and potential problems associated with the cleaning techniques are fully explained.	
Safety precautions	Respiratory protection may be required in highly contaminated areas. Gloves and overalls. Waterproof clothing may be required. Normal safety procedures for handling chemicals.	
Waste		
Amount & type	*Amount:* 1.3 kg m^{-2}. *Type:* Water, detergent, dust, contaminated filters.	
Doses		
Averted doses	Dose reductions have not been estimated for this option. It should be noted that the cleaning of surfaces and objects will only reduce doses to people while they are indoors and will be very dependent on the specific situation and the surfaces cleaned.	
Factors influencing averted dose	Consistent application over the contaminated area; need to ensure edges and corners are cleaned. Application of appropriate clean-up to other. indoor surfaces and objects. Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering. Care of application. Need to wash contamination off surfaces and not just move it around the surface or onto another surface. Amount of time spent inside buildings.	
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the indoor environment and contaminated equipment • inhalation of radioactive material resuspended from the floor and other surfaces (may be enhanced over normal levels) • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included.	
Intervention costs		
Operator time	Work rate (m^2/team hr)	<100 (depends on cleaning method and target surfaces)
	Team size (people)	1
Factors influencing costs	Building size. Type of equipment used. Access. Use of personal protective equipment (PPE). Tidiness of houses and amount of 'contents'. Amount of dust/dirt on surfaces.	
Side effects		
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.	
Social impact	Possible damage to building surfaces and objects. Positive benefit of cleaning houses. Maintenance of use of indoor spaces.	
Practical experience	None.	
Key references	Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR.	
Version	2	

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23 Other cleaning methods (scrubbing, shampoo, steam cleaning)

Document history	See Table 3.2. Datasheet developed from separate datasheets in UK Handbook 2005 called ‘Scrubbing’ and ‘Foam/shampoo/steam cleaning’ in EURANOS handbook 2007 and later.

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24 Removal of furniture, soft furnishings and other objects

Objective	To reduce inhalation and external gamma and beta doses arising from contamination on indoor objects, furnishings and fixtures within inhabited areas.
Other benefits	Will remove contamination from indoor surfaces in buildings.
Management option description	Objects, fixtures and furnishings in buildings can be removed. Contamination should be fixed to the surface prior to removal if there is a risk of dust further spreading contamination during the removal process. For upholstery, unfixed carpets and linen, a spray fixative of 10 % glycerol in water can be used; wax polish can be sprayed onto smooth finished furniture to prevent dust spreading during removal.
Target	Indoor objects, fixtures and furnishings in buildings.
Targeted radionuclides	All radionuclides. Not short-lived radionuclides alone.
Scale of application	Small indoor areas in all types of building.
Time of application	Maximum benefit if carried out within a few weeks of deposition when maximum contamination is on the surfaces.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use in listed or other historic buildings and on precious objects.
Environmental constraints	None.
Effectiveness	
Reduction in contamination on the surface	If carried out carefully, these removal processes can remove virtually all the contamination on the surfaces/objects that are removed. However, the process of removing objects may result in the spread of contamination onto other surfaces via dust. The amount of contamination re-distributed will depend on the extent to which contamination is contained prior to the removal.
Reduction in surface dose rates	No estimates made.
Reduction in resuspension	No estimates made.
Technical factors influencing effectiveness	Type and condition of surface as this will affect the amount of dust that is likely to be produced and hence spreading of contamination. Time of operation (the longer the time between deposition and implementation of the option the less effective it will be as contaminated dust may have migrated elsewhere). Consistent application over the contaminated area; need to ensure all the surface material is removed. Amount of dust on surfaces at the time of deposition. Whether any cleaning has already been undertaken. Collection of all removed surface material. Weather at time of deposition; much less material is deposited indoors during wet deposition. Amount of furniture and furnishings and ventilation rates.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Pneumatic chisels. Removing lino tiles from concrete: machine (long reach scaler) to remove tiles stuck to concrete floors. Saws for removing wooden floors. Transport vehicles for equipment and waste.
Utilities and infrastructure	Electricity supply. Roads for transport of equipment and waste.
Consumables	Fuel and parts for transport vehicles.
Skills	Only a little instruction is likely to be required. The method could, therefore, at least partially, be implemented by the population as a self-help measure, after instruction from authorities and provision of safety and other required equipment.
Safety precautions	Gloves and overalls. Personal protective equipment (PPE), including respiratory protection, may be required under dusty conditions to reduce resuspension hazard.
Waste	
Amount and type	*Amount:* 20 – 30 kg m^{-2} floor area; removal of fixtures: 50 kg m^{-2}. *Type:* solid waste (e.g. beds, furniture, soft furnishings, ornaments, fixtures, electrical goods etc.)
Doses	

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24 Removal of furniture, soft furnishings and other objects

Averted doses	Dose reductions have not been estimated for this option. It should be noted that removal of fixtures, furniture etc will only reduce doses to people while they are indoors and will be very dependent on the specific situation and the surfaces cleaned.
Factors influencing averted dose	Consistency in effective implementation of option over entire area. Weather at time of deposition; less material is deposited indoors during wet deposition. Application of appropriate clean-up to other indoor surfaces and objects. Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering and cleaning. Care of application. Need to remove contamination from the building and not just move it onto another surface. Amount of time spent inside buildings.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment • external exposure from indoor environment and contaminated equipment • inhalation of radioactive material resuspended from the floor and other surfaces (may be enhanced over normal levels) • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included.
Intervention costs	
Operator time	Work rate (m^2/team hr): typically 20 – 30; Team size (people): 2
Factors influencing costs	Building size. Condition of objects to be removed. Access. Use of personal protective equipment (PPE).
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	Possible damage to building surfaces. Positive benefit of cleaning houses.
Practical experience	None.
Key references	Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR.
Version	2
Document history	See Table 3.2.

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25 Surface removal

Objective	To reduce inhalation and external gamma and beta doses arising from contamination on indoor surfaces of buildings (primarily floors, walls and ceilings) within inhabited areas.
Other benefits	Will remove contamination from indoor surfaces in buildings.
Management option description	**Paint:** can be removed from underlying plaster using commercial sanders. The technique is likely to produce a lot of dust. However, it may be possible to control this using an improvised vacuum shroud placed around the sander which is connected to a vacuum cleaner. **Plaster:** can be removed using long-reach pneumatic chisels. **Wallpaper:** can be removed by manual scraping or using steam strippers. **Linoleum & carpet:** if not stuck to floors can be manually removed relatively easily. Linoleum tiles stuck to concrete floors may require machinery to remove. For tiles stuck to hardboard, removal involves removing both the hardboard and tiles together by removing the pins and pulling the hardboard away from the floor. **Wooden floors:** are removed by prising the floor boards from the cross joints which are then themselves removed using saws.
Target	Indoor surfaces of buildings.
Targeted radionuclides	All radionuclides. Not short-lived radionuclides alone.
Scale of application	Small areas of indoor surfaces in all types of building.
Time of application	Maximum benefit if carried out within a few weeks of deposition when maximum contamination on surfaces.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use in listed or other historic buildings and on precious objects.
Environmental constraints	None.
Effectiveness	
Reduction in contamination on the surface	If carried out carefully, these removal processes can remove virtually all the contamination on the surface. However, the process of removing paper, paint or plaster may result in the spread of contamination onto other surfaces via dust. Repeated application is unlikely to provide any significant increase in DF if implemented thoroughly the first time.
Reduction in surface dose rates	No estimates made.
Reduction in resuspension	No estimates made.
Technical factors influencing effectiveness	Type and condition of surface. Time of operation (the longer the time between deposition and implementation of the option the less effective it will be as contaminated dust migrates over time). Consistent application over the contaminated area; need to ensure all the surface material is removed. Amount of dust on surfaces at the time of deposition. Collection of all removed surface material. Whether any cleaning has already been undertaken. Weather at time of deposition; less material is deposited indoors during wet deposition. Amount of furniture and furnishings and ventilation rates. Appropriate clean-up of other indoor surfaces and objects.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Scrapers. Steam strippers. Pneumatic chisels. Removing lino tiles from concrete: machine (long reach scaler) to remove tiles stuck to concrete floors. Saws for removing wooden floors. Transport vehicles for equipment and waste.
Utilities and infrastructure	Mains electricity supply. Water supply. Roads for transport of equipment and waste.
Consumables	Fuel and parts for transport vehicles. Water and detergent.

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25 Surface removal

Skills	Only a little instruction is likely to be required.
Safety precautions	Gloves and overalls. Waterproof clothing may be required. Personal protective equipment (PPE) may be required under dusty conditions to reduce the hazard from resuspension. Appropriate safety measures and respiratory protection will be required if asbestos is present.

Waste

Amount and type

Surface removed	Amount (kg m^{-2} solid waste)	Type
Wallpaper	1.0	Wallpaper
Paint	1.0	Paint and plaster dust
Plaster	1 10^{1}	Plaster
Carpet	4 10^{-1}	Carpet
Linoleum / linoleum tiles (laid on concrete)	4	Tiles and hardboard
Wood floor	7	Wood

Any water resulting from steam stripping will not be able to be collected and so floor surfaces will need to be covered and covering disposed of.

Doses

Averted doses	Dose reductions have not been estimated for this option. Some indication of possible dose reductions can be found in Datasheet 27 (washing). However, it should be noted that removal of surfaces will only reduce doses to people while they are indoors and will be very dependent on the specific situation and the surfaces cleaned.
Factors influencing averted dose	Consistency in effective implementation of option over entire area. Weather at time of deposition; less material is deposited indoors during wet deposition. Application of appropriate clean-up to other indoor surfaces and objects. Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering and cleaning. Care of application. Need to remove contamination from surfaces and not just move it around the surface or onto another surface. Amount of time spent inside buildings.

Additional doses

Relevant exposure pathways for workers are:

- external exposure from radionuclides in the indoor environment and contaminated equipment
- inhalation of radioactive material resuspended from the floor and other surfaces (may be enhanced over normal levels)
- *Inadvertent ingestion of dust from workers' hands*

Contributions from pathways in italics will not be significant and doses from these pathways can be controlled by using PPE.

Exposure routes from transport and disposal of waste are not included.

Intervention Costs

Operator time

Surface removed	Work rate (m^2/team.hr)
Wallpaper	60 (scraping) 230 (scraping and peeling) 400 (peeling)
Paint	5 (walls) 4 (ceilings)
Plaster	25 (walls and ceilings)
Carpet	100
Linoleum	80
Linoleum tiles (laid on concrete)	20
Linoleum tiles (laid on wood)	200
Wood floor	3

Team size (people): 2 for carpet removal; 1 for all other techniques

Factors influencing costs

Building size.

Type of equipment used.

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25 Surface removal

	Access. Use of personal protective equipment (PPE). Tidiness of houses and amount of 'contents'. Thickness of surface covering/layers of wallpaper and/or paint.
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	Possible damage to building surfaces. Positive benefit of cleaning houses.
Practical experience	None.
Key references	Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR.
Version	2
Document history	See Table 3.2.

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26 Vacuum cleaning

Objective	To reduce inhalation and external gamma and beta doses arising from contamination on internal surfaces of buildings and indoor objects within inhabited areas.
Other benefits	Will remove contamination from indoor surfaces and objects in buildings.
Management option description	Any domestic or industrial vacuum cleaner can be used to clean surfaces and objects, such as furniture. However, it is preferable to use a vacuum cleaner fitted with HEPA filters of 99 % efficiency to 0.6 µm particles to prevent resuspension. Machines are electrically operated from mains electricity. Will give rise to dust, particularly in dusty environments. Using water to dampen the surface or the use of a tie-down material is unlikely to be practicable and so personal protective equipment (PPE) should be provided for the workers to reduce the resuspension hazard.
Target	Internal surfaces (particularly floors) and objects in buildings.
Targeted radionuclides	All radionuclides. Particularly short-lived radionuclides if implemented quickly.
Scale of application	Suitable for indoor surfaces in all types of building.
Time of application	Maximum benefit within a few weeks of deposition when maximum contamination on surfaces. However, over longer periods, contamination may be brought into buildings e.g. on the soles of shoes, and so repeated application regularly may be beneficial until any surrounding soil or grass areas are cleaned.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use in listed or other historic buildings and on precious objects.
Environmental constraints	None.
Effectiveness	
Reduction in contamination on the surface	Vacuum cleaning of carpets will generally have an insignificant effect on activity concentrations of contaminated particles in the region of size 1µm (as observed with the initial caesium contamination after the Chernobyl accident). However, a fraction of the contamination will rapidly become attached to larger house dust particles (>5 µm), for which vacuum cleaning is effective. Soil particles brought into the buildings on shoes or by the wind will be relatively large and therefore easy to remove. A decontamination factor (DF) of 5 can be achieved, although there is likely to be large variation in this value. The quoted range assumes that this option is implemented within a few weeks of deposition and no previous cleaning has taken place. Repeated application is unlikely to give any significant increase in DF if implemented thoroughly the first time.
Reduction in surface dose rates	External gamma and beta dose rates immediately above the cleaned surface will be reduced by a value similar to the DF.
Reduction in resuspension	Resuspended activity in air will be reduced by a value similar to the DF.
Technical factors influencing effectiveness	Type and condition of surface. Time of operation (the longer the time between deposition and implementation of the option the less effective it will be as contaminated dust migrates over time). Consistent application over the contaminated area; need to ensure edges and corners are cleaned. Amount of dust on surfaces at the time of deposition. Whether any cleaning has already been undertaken. Efficiency of equipment (depends on aerosol size of contaminant). Weather at time of deposition; less material is deposited indoors during wet deposition. Amount of furniture and furnishings in the buildings and ventilation rates.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Vacuum cleaner with brush attachment and upholstery cleaning attachment (preferably HEPA filtered industrial vacuum cleaner). Transport vehicles for equipment and waste.
Utilities and infrastructure	Electricity supply. Roads for transport of equipment and waste.
Consumables	Fuel and parts for transport vehicles.
Skills	Only a little instruction is likely to be required. The method could be implemented by the population as a self-help measure, after instruction from authorities and the provision of safety equipment (PPE).
Safety precautions	Personal protective equipment (PPE), including respiratory protection, will be required because dust may be produced.

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26 Vacuum cleaning

Waste	
Amount and type	*Amount:* 5 10^{-3} kg m^{-2}. *Type:* Dust, contaminated filters (40 g m^{-2} per year) which may have high contamination levels.
Doses	
Averted doses	**Dry deposition:** reductions of approx 15 % in external gamma dose rate received by a member of the public living in an inhabited area could be expected shortly after decontamination of the indoor building surfaces. **Wet deposition:** reductions in dose-rates will be negligible.

Cs-137 (% reduction in external dose)				Pu-239 (% reduction in resuspension dose)			
Over 1st year		Over 50 years		Over 1st year		Over 50 years	
Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
<5	<5	<5	<5	35-40	<5	35-40	<5

The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area and assume application to all indoor surfaces.

Factors influencing averted dose	Consistent application over the contaminated area; need to ensure edges and corners are cleaned. Weather at time of deposition; less material is deposited indoors during wet deposition. Initial deposition is also influenced by the amount of furniture and ventilation rates. Application of appropriate clean-up to other indoor surfaces and objects. Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering. Amount of time spent inside buildings.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the indoor environment and contaminated equipment • inhalation of radioactive material resuspended from the floor and other surfaces (may be enhanced over normal levels) • inhalation of dust generated • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included.
Intervention costs	

Operator time	Work rate (m^2/team hr)	1.2 10^2 – 1.5 10^2 For cleaning upholstery and soft furnishings: 25 m^2 hr^{-1}
	Team size (people)	1

Factors influencing costs	Building size. Type of equipment used. Access. Use of personal protective equipment (PPE). Tidiness of houses and amount of 'contents'. Amount of dust/dirt on surfaces.
Side effects	
Environmental impact	Disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	Possible damage to indoor building surfaces and objects. Positive benefit of cleaning houses.
Practical experience	Several small scale tests have been reported before/after the Chernobyl accident in 1986.
Key references	Allott RW, Kelly M and Hewitt CN (1994). A model of environmental behaviour of contaminated dust and its application to determining dust fluxes and residence times. *Atmospheric Environment*, **28**, (4), 679-687. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315.

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26 Vacuum cleaning

	Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Roed J (1985). *Relationships in indoor/outdoor air pollution.* Risø-M-2476, Risø national Laboratory, Roskilde, Denmark. Tschiersch J (ed.) (1995). Deposition of radionuclides, their subsequent relocation in the environment and resulting implications. EUR 16604 EN, ISBN 92-827-4903-7.
Version	2
Document history	See Table 3.2. Information from datasheet 'Intensive indoor surface cleaning' in STRATEGY 2006 split into 2 datasheets – 'vacuum cleaning' and 'washing' in UK Handbook 2005 and later.

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27 Washing

Objective	To reduce inhalation and external gamma and beta doses arising from contamination on internal surfaces of buildings and indoor objects within inhabited areas.
Other benefits	Will remove contamination from indoor surfaces and objects in buildings.
Management option description	**Hard surfaces and objects:** wash with warm/hot water and detergent. Surfaces need to be rinsed to remove any remaining contamination / detergent. **Upholstered surfaces:** detergent solution can be sprayed onto the surface and is vacuumed off. **Walls and ceilings:** sheeting should be used to prevent contamination of the floor with waste water. It should be possible to collect the water.
Target	Indoor hard surfaces, particularly floors, and objects in buildings.
Targeted radionuclides	All radionuclides. Particularly short-lived radionuclides if implemented quickly.
Scale of application	Indoor surfaces in all types of building.
Time of application	Maximum benefit if carried out within a few weeks of deposition when maximum contamination on surfaces.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use in listed or other historic buildings and on precious objects.
Environmental constraints	None
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of 5 can be achieved, although there is likely to be a large variation in this value. The quoted DF assumes that this option is implemented within a few weeks of deposition and no previous cleaning has taken place. Repeated application is unlikely to provide any significant increase in DF if implemented thoroughly the first time.
Reduction in surface dose rates	External gamma and beta dose rates from internal surfaces of buildings will be reduced by the value of the DF.
Reduction in resuspension	Resuspended activity in air will be reduced by a value similar to the DF.
Technical factors influencing effectiveness	Type and condition of surface. Time of operation (the longer the time between deposition and implementation of the option the less effective it will be as contaminated dust migrates over time). Consistent application over the contaminated area; need to ensure edges and corners are cleaned. Amount of dust on surfaces at the time of deposition. Whether any cleaning has already been done. Efficiency of equipment. Solubility of contaminating radionuclides. Weather (less material is deposited indoors during wet deposition). Appropriate clean-up of other indoor surfaces and objects. Care of application. Need to wash contamination off surfaces and not just move it around the surface or onto another surface. Ability to wash objects.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Wet vacuum cleaner. Detergent sprayer. Rotating brush. PVC sheeting. Transport vehicles for equipment and waste.
Utilities and infrastructure	Electricity supply. Water supply. Roads for transport of equipment and waste.
Consumables	Fuel and parts for transport vehicles. Water and detergent.
Skills	Only a little instruction is likely to be required. The method could, at least partially, be implemented by the population as a self-help measure, after instruction from authorities and provision of safety and other required equipment.
Safety precautions	Gloves and overalls.

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<table>
<tr><td></td><td colspan="8">Waterproof clothing may be required.
Normal safety procedures for handling chemicals.</td></tr>
<tr><td colspan="9">Waste</td></tr>
<tr><td>Amount & type</td><td colspan="8"><i>Amount:</i> 1 10^{-3} – 2 10^{-3} kg m^{-2}.
<i>Type:</i> Dust and water.</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td rowspan="5">Averted doses</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239 (% reduction in resuspension dose)</td></tr>
<tr><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td><5</td><td><5</td><td><5</td><td><5</td><td>35-40</td><td><5</td><td>30-35</td><td><5</td></tr>
<tr><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area and assume application to all indoor surfaces.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Consistent application over the contaminated area; need to ensure edges and corners are cleaned.
Weather at time of deposition; less material is deposited indoors during wet deposition.
Application of appropriate clean-up to other indoor surfaces and objects.
Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Care of application. Need to wash contamination off surfaces and not just move it around the surface or onto another surface.
Amount of time spent inside buildings.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the indoor environment and contaminated equipment
• inhalation of radioactive material resuspended from the floor and other surfaces (may be enhanced over normal levels)
• inhalation of dust generated
• <i>inadvertent ingestion of dust from workers' hands</i>
Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE.
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td rowspan="2">Operator time</td><td colspan="2">Work rate (m^2/team hr)</td><td colspan="6">15 – 30 depending on type of surface</td></tr>
<tr><td colspan="2">Team size (people)</td><td colspan="6">1</td></tr>
<tr><td>Factors influencing costs</td><td colspan="8">Building size.
Type of equipment used.
Access.
Use of personal protective equipment (PPE).
Tidiness of houses and amount of ‘contents’.
Amount of dust/dirt on surfaces.</td></tr>
<tr><td colspan="9">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="8">The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.</td></tr>
<tr><td>Social impact</td><td colspan="8">Possible damage to building surfaces and objects.
Positive benefit of cleaning houses.</td></tr>
<tr><td>Practical experience</td><td colspan="8">Several small scale tests have been reported before/after the Chernobyl accident in 1986.</td></tr>
<tr><td>Key references</td><td colspan="8">Allott RW, Kelly M and Hewitt CN (1994). A model of environmental behaviour of contaminated dust and its application to determining dust fluxes and residence times. <i>Atmospheric Environment</i>, 28, (4), 679-687.
Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). <i>Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.</i> Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark.
Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315.
Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination</td></tr>
</table>

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27 Washing

	options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Roed J (1985). *Relationships in indoor/outdoor air pollution.* Risø-M-2476, Risø national Laboratory, Roskilde, Denmark. Tschiersch J (ed.) (1995). Deposition of radionuclides, their subsequent relocation in the environment and resulting implications. EUR 16604 EN, ISBN 92-827-4903-7.
Version	2
Document history	See Table 3.2. Information from datasheet 'Intensive indoor surface cleaning' in STRATEGY 2006 split into 2 datasheets – 'vacuum cleaning' and 'washing' in UK Handbook 2005 and later.

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28 Storage, shielding, covering, gentle cleaning of precious objects

Objective	To reduce inhalation and external gamma and beta doses arising from contamination on personal and precious objects within inhabited areas. This option is likely to be implemented primarily for public reassurance as exposure from personal and precious objects is unlikely to be a significant contribution to an individual's dose.
Other benefits	Gentle cleaning will remove contamination from precious objects within buildings.
Management option description	It may not be possible or appropriate to carry out decontamination of precious objects, such as museum artefacts, tapestries, jewellery, paintings etc. because of the risk of damaging the objects during the cleaning process. Several alternative options are available for such objects. If objects are placed within rooms or storage facilities to which people do not have general access, significant reductions in dose rates to persons in adjoining rooms and buildings can be achieved. Some objects, which do not require handling, could be shielded or covered. For instance, museum artefacts could be placed behind leaded glass or Perspex; they can remain on display, but the public will be shielded from the contamination. Specialist, gentle cleaning techniques could be carried out on objects.
Target	Precious and personal objects within buildings.
Targeted radionuclides	All radionuclides. The storage option will be particularly suitable for short-lived radionuclides. Shielding and covering will be particularly effective for beta emitters.
Scale of application	Small objects.
Time of application	Maximum benefit if carried out soon after deposition.
Constraints	
Legal constraints	Liabilities for possible damage to objects. Ownership and access to objects. Use in listed or other historic buildings.
Environmental constraints	None
Effectiveness	
Reduction in contamination on the surface	Contamination on the surface of objects will only be reduced if gentle cleaning is applied.
Reduction in surface dose rates	**Cleaning:** reduces surface doses rates from objects. **Shielding and storage:** reduces external gamma and beta dose rates; the degree of reduction will depend on the thickness of shielding used. Some examples are given below. **Brick or concrete wall**: thicknesses of 10-20 cm will half the dose rate outside a room for medium to high energy gamma emitters. **Lead**: around 10 mm lead will be sufficient to half the gamma dose rate for many radionuclides. A few centimetres could reduce gamma dose-rates by a factor of 10. **Glass**: 1-5 mm will totally absorb beta particles for the range of beta energies likely to be of concern. Plastic (Perspex) would need to be about twice as thick to have the same effect. **Air**: can also be used as a shielding material. 1-2 m of air will reduce dose-rates to very low levels for weak beta emitters: a distance of up to 10 m would be needed to give high reductions in dose rate for high energy beta emitters such as ^{90}Sr/^{90}Y. For gamma emitters, dose rates will drop off in air in proportion to the square of the distance, e.g., if people are kept 5 m away from an object, the dose-rate they receive from that object will be 25 times lower than if they were 1 m away.
Reduction in resuspension	**Removing contamination:** reduces contamination available for resuspension. **Shielding:** in a closely fitting container will stop all resuspension.
Technical factors influencing effectiveness	Type, condition and fragility of object. Time of operation (contamination migrates elsewhere over time). Consistent application of cleaning over entire object. Amount of dust on the surface of the object at the time of deposition. Whether any cleaning has already been undertaken. Weight of shielding material that can be used and any need to be able to view objects clearly.
Social factors influencing effectiveness	None
Feasibility	
Equipment	Specialist cleaning equipment for gentle cleaning. Specialist lifting equipment, if object is to be moved into storage.
Utilities and infrastructure	Power and water supplies. Storage facilities.
Consumables	Shielding materials.

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28 Storage, shielding, covering, gentle cleaning of precious objects

Skills	Specialist cleaning skills. Specialist handling skills.	
Safety precautions	Gloves and overalls.	
Waste		
Amount and type	Waste water will be generated from cleaning. Quantities are unlikely to be large.	
Doses		
Averted doses	Not estimated. Cleaning objects will only reduce doses to people while they are indoors and will be very dependent on the specific situation and the objects and other surfaces cleaned.	
Factors influencing averted dose	Weather at time of deposition; less material is deposited indoors during wet deposition. Appropriate clean-up of other indoor surfaces and objects.	
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the floor and other surfaces (may be enhanced over normal levels) • enhanced resuspension of activity deposited in the indoor environment leading to inhalation of dust generated Exposure routes from transport and disposal of waste are not included.	
Intervention costs		
Operator time	Work rate (m^2/team hr)	Cleaning of precious objects is likely to take significantly longer than normal cleaning (see Datasheet 27).
	Team size (people)	N/A
Factors influencing costs	None	
Side effects		
Environmental impact	None	
Social impact	Possible damage of objects with particular heritage significance. Lack of access to objects and buildings by the public.	
Practical experience	None	
Key references	Crick MJ and Dimbylow PJ (1985). GRINDS – A computer program for evaluating the shielding provided by buildings from gamma radiation emitted from radionuclides deposited on ground and urban surface. NRPB, Chilton, NRPB-M119. Delacroix D, Guerre JP, Leblanc P and Hickman C (2002). Radionuclide and radiation protection data handbook 2002. *Radiation Protection Dosimetry*, **98**, (1), 1-168.	
Version	2	
Document history	See Table 3.2.	

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29 Firehosing

Objective	To reduce inhalation and external gamma and beta doses from contamination on roads, paved and other outdoor areas with hard surfaces within inhabited areas.
Other benefits	Removal of contamination from roads, paved and other outdoor areas with hard surfaces.
Management option description	Ordinary firehosing equipment is used to hose contaminated material from hard outdoor surfaces. Contamination, dirt/dust and water are washed directly down drains or onto grass and soil verges. It is probably not practicable to collect water from firehosing paved areas. However, collection of water may be possible through the use of bunds, i.e. constraining the water within an area thus allowing it to be subsequently pumped to tankers (this is not considered further in this datasheet).
Target	Outdoor hard surfaces (roads, pavements, paths, playgrounds etc).
Targeted radionuclides	All radionuclides. Short-lived radionuclides if implemented quickly.
Scale of application	Any size road or paved area.
Time of application	Maximum benefit if carried out within about 1 week of deposition as effectiveness depends on removal of dust from the surface. Unlikely to have a significant effect at later times.
Constraints	
Legal constraints	Liabilities for possible damage to property (e.g. flooding). Ownership and access to property. Disposal of contaminated water via public sewer system. Use on listed sites and conservation areas.
Environmental constraints	Severe cold weather. Firehosing should not be considered if hard surfaces are not equipped with drains.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of 5 following dry deposition and 2 following wet deposition, can be achieved if this option is implemented within one week of deposition and there has been no significant rain. DFs at longer times will be significantly lower unless surface has not been subject to any 'traffic' and there has been no rainfall. Since weathering will reduce contamination from these surfaces rapidly, the effectiveness of the method will decrease with time and after a few months is unlikely to remove significant contamination. Repeated application is unlikely to provide any significant increase in DF. In the short term, the quoted DF can be considered to be the same for all radionuclides, with the exception of elemental iodine and tritium, for which thorough hosing of impermeable surfaces will lead to virtually full removal.
Reduction in surface dose rates	External gamma and beta dose rates above a 'paved' surface will be reduced by the value of the DF.
Reduction in resuspension	Resuspended activity in air will be reduced by the value of the DF.
Technical factors influencing effectiveness	Amount of dust on surface at time of contamination. Type, evenness and condition of surface. Road gutters must be hosed carefully because contamination tends to accumulate there. Time of operation (the longer the time between deposition and implementation of the option the less effective it will be due to fixing of the contamination to the surface and migration of dust from the surface). Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Weather: effectiveness is significantly reduced after rain. Consistent application of water over the contaminated area. Amount of hard outdoor surfaces in the area. Whether decontamination is carried out on adjacent surfaces. Run-off of contamination onto other outdoor surfaces.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Fire hose. Hydrant or fire fighting appliance. Pump, if required.
Utilities and infrastructure	Water supply.
Consumables	Water. Fuel and parts for equipment.

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<table>
<tr><td>Skills</td><td colspan="8">Skilled personnel essential to operate fire fighting appliances and hoses.</td></tr>
<tr><td>Safety precautions</td><td colspan="8">Water-resistant clothing would be recommended, particularly in highly contaminated areas.
Personal protective equipment (PPE), including respiratory protection.
Precautions are needed to ensure that people making connections to mains water supplies do not inadvertently contaminate the water supply, e.g. by back-flow from vessels containing radioactivity or other contaminants, or operate hydrants in a way that disturbs settled deposits within the water main system.</td></tr>
<tr><td colspan="9">Waste</td></tr>
<tr><td>Amount and type</td><td colspan="8"><i>Amount:</i> $1\ 10^{-1} – 2\ 10^{-1}$ kg m^{-2} solid in up to 50 l m^{-2} water.
<i>Type:</i> dust and water.</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td rowspan="5">Averted doses</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239 (% reduction in resuspension dose)</td></tr>
<tr><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td><5</td><td>5-10</td><td><5</td><td>5-10</td><td><5</td><td>5-10</td><td><5</td><td>5-10</td></tr>
<tr><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Consistency in effective implementation of option over a large area.
Population behaviour in area.
Amount of hard outdoor surfaces in the area ie environment type/land use.
Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Whether decontamination is carried out on adjacent paved surfaces.
Run-off of contamination onto other outdoor surfaces.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)
• inhalation of water spray generated
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td>Operator time</td><td colspan="8">$1\ 10^{3}$ m^{2}/team.hr.
(Team size: 2 – 3 people depending on type of equipment used).</td></tr>
<tr><td>Factors influencing costs</td><td colspan="8">Weather.
Topography.
Size of area to be treated.
Type of equipment used.
Access.
Proximity of water supplies.
Use of personal protective equipment (PPE).</td></tr>
<tr><td colspan="9">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="8">Run-off from firehosing (if not collected) will flow onto other surfaces or directly down drains. The environmental impact of disposal of waste water from firehosing directly to drains may be easier to control and monitor in the sewage treatment plant than long term run-off produced by rainfall.
The disposal of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Run-off of contamination onto other outdoor surfaces which may lead to more waste being generated if these areas subsequently require decontaminating.</td></tr>
<tr><td>Social impact</td><td colspan="8">Acceptability of active disposal of contaminated waste water into the public sewer system.
Firehosing of roads and pavements will make an area look clean; implementation may give public reassurance.</td></tr>
<tr><td>Practical experience</td><td colspan="8">Small-scale tests conducted in Denmark and USA under varying conditions to examine the influence of e.g. street dust loading.</td></tr>
<tr><td>Key references</td><td colspan="8">Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2.
Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R,</td></tr>
</table>

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	Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, **46**, (2), 207-223. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Roed J (1990). *Deposition and removal of radioactive substances in an urban area.* Final report of the NKA Project AKTU-245, Nordic Liaison Committee for Atomic Energy, ISBN 87-7303-514-9 Roed J and Andersson KG (1996). Clean-up of urban areas in the CIS countries contaminated by Chernobyl fallout. *Journal of Environmental Radioactivity*, **33** (2), 107-116. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p. Warming L (1984). Weathering and decontamination of radioactivity deposited on concrete surfaces. Risø-M-2473, Risø National Laboratory, Roskilde, Denmark.
Version	2
Document history	See Table 3.2.

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30 High pressure hosing

Objective	To reduce inhalation and external gamma and beta doses from contamination on roads, paved and other outdoor areas with hard surfaces within inhabited areas.
Other benefits	Removal of contamination from roads, paved and other outdoor areas with hard surfaces within inhabited areas.
Management option description	Water is applied to the surface at high pressure (approx 2000 psi). It is unlikely that it will be practicable to collect the waste water from high pressure hosing and waste will be washed directly down the drain. However, if collection is practicable, segregation of contaminated dust from the water may be possible by filtration of the aqueous waste. Workers may need to be protected against water spray.
Target	Outdoor hard surfaces (roads, pavements, paths, playgrounds etc.).
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides alone.
Scale of application	Any size road or paved area
Time of application	Maximum benefit if carried out soon after deposition. However, high pressure hosing may be effective up to several years after deposition, depending on the amount of traffic and heavy rainfall.
Constraints	
Legal constraints	Liabilities for possible damage to property (e.g. flooding). Ownership and access to property. Disposal of contaminated water via public sewer system. Use on listed sites or in conservation areas.
Environmental constraints	Severe cold weather. High pressure hosing should not be considered if hard surfaces are not equipped with drains if waste water is not being collected.
Effectiveness	
Reduction in contamination on the surface	Decontamination factors (DF) of 7 following dry deposition and 3 following wet deposition, can be achieved if this option is implemented soon after deposition. Since the contamination will be removed rapidly from these surfaces through natural processes, the effectiveness of the method will decrease with time, depending on the amount of traffic and rainfall. Repeated application is unlikely to provide any significant increase in DF. In the short term, the quoted DF can be considered to be same for all radionuclides, with the exception of elemental iodine and tritium, for which thorough washing of impermeable surfaces will lead to virtually full removal.
Reduction in surface dose rates	External gamma and beta dose rates above a 'paved' surface will be reduced by the value of the DF.
Reduction in resuspension	Resuspended activity in air above the surface will be reduced by the value of the DF.
Technical factors influencing effectiveness	Type, evenness and condition of surface. Road gutters must be hosed carefully because contamination tends to accumulate here. Time of operation: the longer the time between deposition and implementation of the option the less effective it will be due to fixing of the contamination to the surface. Consistent application of water over the area. Amount of hard outdoor surfaces in the area. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Whether decontamination is carried out on adjacent surfaces. Run-off of contamination onto other outdoor surfaces.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	2000 psi pressure washer. Spate pump. Filter. Transport vehicles. 7.5 kW generator. (Depends on whether waste water is collected or not.)
Utilities and infrastructure	Roads (transport of equipment, materials and waste). Water supply. Public sewer system.
Consumables	Water. Sand.

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30 High pressure hosing

<table>
<tr><td></td><td colspan="8">Fuel and parts for equipment, generators and transport vehicles.</td></tr>
<tr><td>Skills</td><td colspan="8">Skilled personnel essential to operate high pressure hoses and gully suckers.</td></tr>
<tr><td>Safety precautions</td><td colspan="8">Water-resistant clothing should be recommended, particularly in highly contaminated areas.
The use of personal protective equipment (PPE), including respiratory protection, may be advisable due to the proximity to contaminated water spray.
Precautions are needed to ensure that people making connections to mains water supplies do not inadvertently contaminate the water supply, e.g. by back-flow from vessels containing radioactivity or other contaminants, or operate hydrants in a way that disturbs settled deposits within the water main system.</td></tr>
<tr><td colspan="9">Waste</td></tr>
<tr><td>Amount</td><td colspan="8">$2\ 10^{-1} – 4\ 10^{-1}$ kg m^{-2} solid; 20 l m^{-2} water.</td></tr>
<tr><td>Type</td><td colspan="8">Dust and water.
Unlikely to be possible to collect waste water.</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td rowspan="5">Averted doses</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239 (% reduction in resuspension dose)</td></tr>
<tr><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td><5</td><td>10-15</td><td><5</td><td>5-10</td><td>0</td><td><5</td><td><5</td><td>5-10</td></tr>
<tr><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Consistency in effective implementation of option over a large area.
Population behaviour in area.
Amount of hard outdoor surfaces in the area ie environment type/land use.
Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Whether decontamination is carried out on adjacent paved surfaces.
Run-off of contamination onto other outdoor surfaces.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)
• inhalation of dust and water spray generated
• *inadvertent ingestion of dust from workers' hands*
Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE.
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td rowspan="2">Operator time</td><td colspan="3">Work rate (m^2/team.hr)</td><td colspan="5">30 – 60 (excludes setting up scaffolding)</td></tr>
<tr><td colspan="3">Team size (people)</td><td colspan="5">2 – 5 (depends on equipment used for access to buildings)</td></tr>
<tr><td>Factors influencing costs</td><td colspan="8">Weather.
Topography.
Size of area to be treated.
Type of equipment used.
Access.
Proximity of water supplies.
Use of personal protective equipment (PPE).</td></tr>
<tr><td colspan="9">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="8">The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Run-off of contamination onto other outdoor surfaces which may lead to more waste being generated if these areas subsequently require decontaminating.</td></tr>
<tr><td>Social impact</td><td colspan="8">Acceptability of active disposal of contaminated waste water into the public sewer system.
Acceptability of disposal of filtered waste from contaminated water.
High pressure hosing of roads and pavements will make an area look clean; implementation may give public reassurance.</td></tr>
</table>

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30 High pressure hosing

Practical experience	Small scale experiments have been carried out in Denmark.
Key references	Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR.
Version	2
Document history	See Table 3.2.

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31 Surface removal and replacement

Objective	To reduce inhalation and external gamma and beta doses from contamination on roads, paved and other outdoor areas with hard surfaces within inhabited areas.
Other benefits	Removal of contamination from roads and paved areas.
Management option description	The most common forms of hard outdoor surfaces will be tarmac or concrete slabs. Standard machinery to remove asphalt surfaces is available in different sizes. They have a rotating drum with cutting teeth which conveys planed material (about 40 mm thick) to the middle of drum where it is pushed on to a conveyor belt and from there to flat bed truck. If machines do not have brushes for debris collection, this must be added or manual sweeping carried out. Water is sprayed continuously onto the drum to suppress dust. Typical highway maintenance machinery can remove a width of about 2 m per pass. Replacing/resurfacing asphalt and concrete roads can be undertaken using standard equipment. For replacement in small areas, manual methods are likely to be used, i.e. tarmac is deposited in several places and spread by shovel and rake, then tamped. For small surface areas it may also be possible to use a jackhammer to loosen existing tarmac and rubble can be shovelled into wheelbarrows. However, this has not been trialled. A small excavator/bob-cat can be used to remove concrete slabs. Concrete slabs are replaced by hand. The need to resurface asphalt and concrete surfaces will depend on the depth removed and other factors, such as acceptability. The area can be repaved with hot rolled asphalt or concrete paving machine to relay concrete. This option is likely to give rise to dust, so application of water to dampen the surface or the use of a tie-down material (Datasheet 32) is recommended prior to implementation to limit the resuspension hazard.
Target	Hard outdoor surfaces (roads, pavements, paths, playgrounds etc.).
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides alone.
Scale of application	Any size road or paved area.
Time of application	Maximum benefit if carried out soon after deposition when maximum contamination is on the surfaces. However surface removal can be effective up to 10 years after deposition.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use in conservation areas or at listed sites.
Environmental constraints	If the surface of the road is cambered the removal depth will not be uniform.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of 5 - 10 can be achieved. Reductions in external and resuspension doses received by a member of public living in the area will depend on the amount of the area covered by outdoor hard surfaces and the time spent by individuals on or close to these areas (see below). Repeated application is unlikely to provide any significant increase in DF.
Reduction in surface dose rates	External gamma and beta dose rates and resuspension above a 'paved' surface will be reduced by the value of the DF.
Reduction in resuspension	Resuspended activity in air above the surface will be reduced by the value of the DF.
Technical factors influencing effectiveness	Evenness and condition of roads. Operator skill. Ineffective removal of contamination around drains and in gutters. Removal of loose debris from surface. Consistency in effective implementation of option over a large area. Amount of hard outdoor surfaces in the area. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Whether decontamination is carried out on adjacent surfaces.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Requirements	
Equipment	The equipment used for surface removal and replacement will depend on the size of the area being treated.

Small areas	Large areas
Small scale planer Shovel Tamper	Planer with conveyor Paving machine Road sweeper

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31 Surface removal and replacement

<table>
<tr><td rowspan="2"></td><td colspan="4">Wheelbarrow
Lorry</td><td colspan="4">Roller
JCB
Lorry</td></tr>
<tr><td colspan="8">Transport vehicles for equipment and waste.</td></tr>
<tr><td>Utilities and infrastructure</td><td colspan="8">Roads (transport of equipment, materials and waste).</td></tr>
<tr><td>Consumables</td><td colspan="8">Tarmac or concrete or concrete paving slabs.
Tungsten carbide teeth.
Fuel and parts for equipment, generators and vehicles.</td></tr>
<tr><td>Skills</td><td colspan="8">Skilled personnel essential to operate equipment.</td></tr>
<tr><td>Safety precautions</td><td colspan="8">Gloves.
Safety goggles.
Safety helmets.
Respiratory protective equipment (RPE).</td></tr>
<tr><td colspan="9">Waste</td></tr>
<tr><td>Amount</td><td colspan="8">Asphalt: about 15 kg m^{-2} per cm removed.
Paving slabs (concrete): about 30 kg m^{-2} per cm removed.
Waste depends on thickness removed and density of material.</td></tr>
<tr><td>Type</td><td colspan="8">Paving slabs, concrete and asphalt.</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td rowspan="5">Averted doses</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239 (% reduction in resuspension dose)</td></tr>
<tr><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td><5</td><td>15-20</td><td><5</td><td>10</td><td>0</td><td>5-10</td><td><5</td><td>10-15</td></tr>
<tr><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Consistency in effective implementation of option over a large area.
Population behaviour in area.
Amount of hard outdoor surfaces in the area i.e. environment type/land use.
Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Whether decontamination is carried out on adjacent paved surfaces.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td rowspan="2">Operator time</td><td colspan="2">Work rate (m^2/team.hr)</td><td colspan="6">Asphalt: 4 10^2 – 1 10^3
Paving slabs (concrete): 4 – 30</td></tr>
<tr><td colspan="2">Team size (people)</td><td colspan="6">Asphalt: 2 – 4; Paving slabs (concrete): 2
Team of 14 needed if road surface replaced and a team of 4 for paving slab replacement</td></tr>
<tr><td>Factors influencing costs</td><td colspan="8">Weather.
Evenness and condition of surface (affects grinding depth).
Size of area to be treated.
Type of equipment used / planer size / sweeping equipment.
Access.
Use of personal protective equipment (PPE).</td></tr>
<tr><td colspan="9">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="8">Road and pavement condition may be improved providing tarmac or concrete has been laid properly.
The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.</td></tr>
<tr><td>Social impact</td><td colspan="8">Method of disposing such a large quantity of contaminated waste may not be acceptable to local residents.
Disruption of access if people remain in the area.</td></tr>
</table>

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31 Surface removal and replacement

	May improve road conditions.
Practical experience	Tested on a small scale in the Former Soviet Union, pre-Chernobyl tests in the USA.
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, **46**, (2), 207-223. Barbier MM and Chester CV (1990). *Decontamination of large horizontal concrete surfaces outdoors.* Proc. Concrete Decontamination Workshop, 28-29 May 1980, CONF-800542, PNL-SA-8855. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Calvert S, Brattin H and Bhutra S (1984). *Improved street sweepers for controlling urban particulate matter.* A.P.T. Inc., 4901 Morena Blvd., Suite 402, San Diego, CA 97117, EPA-600/7-84-021. Roed J (1990). *Deposition and removal of radioactive substances in an urban area.* Final report of the NKA Project AKTU-245, Nordic Liaison Committee for Atomic Energy, ISBN 87-7303-514-9. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p.
Version	2
Document history	See Table 3.2. Called 'Road planing' in STRATEGY 2003.

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32 Tie-down (fixing contamination to the surface)

Objective	To reduce inhalation doses from material resuspended from roads, paved and other outdoor areas with hard surfaces within inhabited areas in the short or long term (depending on the tie-down material used). Also used to prevent enhanced resuspension during implementation of options that create dust, particularly in dusty environments.
Other benefits	May also reduce external beta doses.
Management option description	Water, sand or bitumen can be used for tie-down of contamination on outdoor hard surfaces. The procedure implemented is dependent on which tie-down material is used and the size of the area being treated. **Water** (temporary tie-down): unlikely to be effective during wet weather. Water is sprayed onto the surface from a sprinkler boom mounted on a vehicle. A meniscus is formed between the radioactive particles and the paved surface; surface tension prevents resuspension. **Sand** (temporary tie-down): For small areas, sand is shovelled by hand from a lorry on to the paved surface. For large areas, about 1mm of sand is sprinkled on to the paved surface using a lorry fitted with a rotary motorised sprinkler. **Bitumen** (permanent tie-down): For small areas, hot bitumen is sprayed onto the surface. A tank with a capacity of about 2000 - 3000 litres is required which can be moved by a four-wheel drive vehicle. The coating is permanent. For large areas, hot bitumen is sprayed onto the surface via a bulk surface-dressing machine. In both cases, if the surface is damp, a bitumen emulsion should be applied. When spraying bitumen, account should be taken of ironworks (e.g. drain covers) etc within the surface being covered. **Peelable coatings** will also give protection against the resuspension hazard while they are in place (Datasheet 49). Depending on the objective (long or short term tie-down) and the tie-down material used, repeated application may be necessary to maintain the integrity of the covering.
Target	Hard outdoor surfaces (roads, pavements, paths, playgrounds etc).
Targeted radionuclides	Alpha emitting radionuclides.
Scale of application	Any size road or paved area.
Time of application	Can be effective at any time after deposition; however, maximum benefit in terms of reducing overall doses if carried out soon after deposition when maximum contamination is on the surfaces. Tie-down is effective for the period over which the integrity of the covering is maintained.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Waste disposal legislation.
Environmental constraints	Severe cold weather.
Effectiveness	
Reduction in contamination on the surface	This option is not applied to clean-up a surface. It is assumed that the decontamination factor (DF) is 1. In practice, some contamination may be removed along with the tie-down material (if it is removed). In the long-term, account should be taken of the need for surface repair and access to underlying services (e.g. gas/water pipes, cables).
Reduction in surface dose rates	While the tie-down material is in place, external beta dose rates adjacent to the surface will be reduced; the reduction will depend on the energy of the beta emissions, the tie-down material and its thickness (see Section 2.1 and Appendix A).. Sand (2 mm) would be the most effective at reducing beta dose rates, bitumen (1 mm) and water (1 mm) will give less protection. For example, for ^{90}Sr and its daughter ^{90}Y, which is a strong beta emitter, reduction of 90 % for sand, 70 % for bitumen and 45 % for water could be expected. This option is not effective at reducing external gamma dose rates adjacent to the surface.
Reduction in resuspension	Resuspended activity in air will be reduced by a factor close to 100 while the tie-down material is in place.
Technical factors influencing effectiveness	Weather conditions. Correct application of tie-down material over the contaminated area. Type, evenness and condition of surface. Water and foam application is not suitable for surfaces on slopes. Amount of paved surface. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Length of time tie-down material is in place.
Social factors influencing	None

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32 Tie-down (fixing contamination to the surface)

effectiveness	
Feasibility	
Equipment	(Depends on the material used for tie-down.) **Water:** a motorised street washer is required. **Sand:** a lorry, sprinkler attachment and JCB loader are required. **Bitumen:** a hot bitumen sprayer or cold emulsion sprayer are required. In **all cases**, transport vehicles for equipment are required.
Utilities and infrastructure	Roads (transport of equipment, materials and waste). Water supply.
Consumables	Water supply. Sand. Hot bitumen or bitumen emulsion. Fuel and parts for transport vehicles and equipment.
Skills	Skilled personnel essential to operate equipment.
Safety precautions	Water-resistant clothing should be recommended when using water. Gloves and overalls for applying bitumen. Precautions are needed to ensure that people making connections to mains water supplies do not inadvertently contaminate the water supply, e.g. by back-flow from vessels containing radioactivity or other contaminants, or operate hydrants in a way that disturbs settled deposits within the water main system.

Waste			
	Water	Sand	Bitumen
Amount	3 10^{-1} l m^{-2}	1 – 2 kg m^{-2}	No waste because this is a permanent tie-down option**
Type	Water and dust	Sand and dust	None
	Removed material used for temporary tie-down may be contaminated. Monitoring would be required to determine if normal disposal routes can be used. ** If bitumen layer is removed in the future, typical quantities of waste from the applied layer would be 1 – 2 kg m^{-2}.		

Doses	
Averted doses	Not estimated. Tie-down will only be effective in reducing resuspension doses from a surface for the period that the tie-down material is in place. The effectiveness in reducing doses to a person living in an inhabited area will be very dependent on the specific situation and the length of time the tie-down material is in place.
Factors influencing averted dose	Effective implementation of option over a large area. Population behaviour in area. Amount of paved surface in the area i.e. environment type/land use. Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering. Length of time tie-down material is in place.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) • inhalation of dust generated • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included.

Intervention costs					
		Water	Sand		Bitumen
			Small areas	Large areas	
Operator time	Work rate (m^{2}/team.hr)	3 10^{4}	5 10^{2}	1 10^{4}	5 10^{2} – 1 10^{3}
	Team size (people)	1	2		2
Factors influencing costs	Weather. Topography. Size of area.				

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32 Tie-down (fixing contamination to the surface)

	Type of equipment used. Access.
Side effects	
Environmental impact	Bitumen spraying roads may provide positive impact if road surfaces are poor. The use of water may wash some of the contamination onto other surfaces. Future maintenance of surfaces e.g. road repairs may give rise to contaminated waste. The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	Acceptability of contamination remaining in-situ. The use of sand for tie-down is a visible indication that a problem exists. Acceptability of future doses to people maintaining roads etc (permanent tie-down materials).
Practical experience	None
Key references	Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR.
Version	2
Document history	See Table 3.2.

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33 Turning paving slabs

Objective	To reduce inhalation and external gamma and beta doses from contamination on roads, paved and other outdoor areas with hard surfaces within inhabited areas.
Other benefits	None
Management option description	Concrete paving slabs are turned over. As the contamination will be attached to the upper surface of the paving slab, turning them will provide shielding against radiation from this contamination. The removal of the slabs prior to turning may give rise to dust, so application of water to dampen the surface or the use of a tie-down material (Datasheet 32) is recommended prior to implementation to limit the resuspension hazard.
Target	Paved surfaces with flagstones (pavements and paths).
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides alone.
Scale of application	Will generally only be suitable for small surface areas (e.g. pavements, paths).
Timing of implementation	Maximum benefit if carried out soon after deposition while maximum contamination remains on the surface.
Constraints	
Legal constraints	Cultural heritage protection, especially in conservation areas or listed sites. Ownership and access to property.
Environmental constraints	None
Effectiveness	
Reduction in contamination on the surface	This option is assumed to have a decontamination factor (DF) of 1 as very little contamination is removed (only that on mortar between slabs will be removed).
Reduction in surface dose rates	External gamma and beta dose rates above the surface will also be reduced. Typically, external gamma dose rates will be reduced by 40-70% for medium to high energy gamma emitters). This option will be very effective at reducing external beta dose rates which will be negligible after implementation.
Reduction in resuspension	The resuspension reduction factor is high (> 100), i.e. resuspension will be stopped.
Technical factors influencing effectiveness	Area covered by paving slabs (the dose rate reduction for a large surface of paving slabs will be greater than that from a small area). Thickness and material characteristics of paving slabs (thick slabs will give more shielding than thin ones). Ease of removal of paving slabs and whether they break on removal. Time of implementation.
Social factors influencing effectiveness	Restrictions on moving slabs in the future.
Feasibility	
Equipment	Spades or similar tools for excavation. Mini excavators. Transport vehicles for equipment.
Utilities and infrastructure	Roads for transport of equipment.
Consumables	Fuel and parts for equipment and transport vehicles. Cement and/or sand. Water. Paving slabs (if need replacing).
Skills	Only a little instruction required.
Safety precautions	Gloves. Safety goggles. Respiratory protective equipment may be required in dusty conditions.
Waste	
Amount and type	No significant waste
Doses	
Averted doses	Not estimated.
Factors influencing averted dose	Consistency in effective implementation of option over a area. Population behaviour in area. Fraction of the area covered by paving slabs. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering. Whether other types of ‘paved’ surfaces’ are also decontaminated.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces

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33 Turning paving slabs

	(may be enhanced over normal levels) • inhalation of dust generated • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included.
Intervention costs	
Operator time	1 – 6 m^2/team.hr. (Team size: 2).
Factors influencing costs	Weather. Topography. Size of area. Type of equipment used. Access. Ease of implementation.
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	Acceptability of contamination remaining in-situ. Surfaces may be visibly less attractive. If paving slabs are not re-laid properly accidents may occur, which may lead to litigation against local authorities.
Practical experience	Only very small experiments have been made, but calculations can demonstrate the potential effectiveness.
Key references	Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). *Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. Roed J (1990). *Deposition and removal of radioactive substances in an urban area.* Final report of the NKA Project AKTU-245, Nordic Liaison Committee for Atomic Energy, ISBN 87-7303-514-9. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p.
Version	2
Document history	See Table 3.2.

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34 Vacuum sweeping

Objective	To reduce inhalation and external gamma and beta doses from contamination on roads, paved and other outdoor areas with hard surfaces within inhabited areas.
Other benefits	Removal of contamination from roads, paved and other outdoor areas with hard surfaces.
Management option description	Municipal vacuum sweepers can be used to clean paved areas. Different types of vacuum sweeper are used for large surface areas, such as roads, and for small surface areas, such as pavements. It is recommended that machines with the ability to dampen the surface with water sprays are used to reduce dust and hence the resuspension hazard. Some road sweepers can operate in wet weather conditions. Liquid waste can be disposed to drains either directly or can be collected. Segregation of the contaminated dust from the water may be possible.
Target	Paved surfaces (roads, pavements, paths, yards, playgrounds etc.).
Targeted radionuclides	All radionuclides. Short-lived radionuclides if implemented quickly.
Scale of application	Any size road or paved area. Unlikely to be used around peoples' houses.
Time of application	Maximum benefit if carried within 1 week of deposition as option relies on removing dust from surface.
Constraints	
Legal constraints	Ownership and access to property. Disposal of contaminated water to public sewer system.
Environmental constraints	Severe cold weather (snow and ice). If waste water is not going to be collected, and the hard surfaces are not equipped with drains, this option should not be considered.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of 2 - 3 can be achieved if this option is implemented within one week of deposition and before rain. The factor is likely to be lower if deposition occurred during rainfall. Since the contamination will be removed rapidly from these surfaces through weathering, the effectiveness of the method will decrease with time and after a few months is unlikely to remove significant contamination. Repeated application is unlikely to provide any significant increase in DF. In the short term, the quoted DF can be considered to be same for all radionuclides, with the exception of elemental iodine and tritium, for which thorough cleaning of impermeable surfaces will lead to virtually full removal. Repeated application is unlikely to provide any significant increase in DF.
Reduction in surface dose rates	External gamma and beta dose rates above a 'paved' surface will be reduced by the value of the DF.
Reduction in resuspension	Resuspended activity in air above the surface will be reduced by the value of the DF.
Technical factors influencing effectiveness	Amount of dust on surface at time of contamination. Particle size of dust. Type, evenness and condition of surface. Road gutters must be cleaned carefully because contamination tends to accumulate here. Time of operation: the longer the time between deposition and implementation of the option the less effective it will be due to fixing of the contamination to the surface. Traffic will remove much of the loose material on the surface, thus reducing the effectiveness of the vacuum sweeping. Consistent application over the contaminated area. The use of water spraying may increase the effectiveness slightly. Amount of hard outdoor surfaces in the area. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Whether decontamination is carried out on adjacent surfaces. Run-off of contamination onto other outdoor surfaces.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Pavement cleaner. Road sweeper. Spate pumps. Storage tanks.
Utilities and infrastructure	Transport vehicles for equipment and waste are required. Public sewer system.

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34 Vacuum sweeping

<table>
<tr><td>Consumables</td><td colspan="8">Fuel and parts for equipment and transport vehicles.
Water for spraying (if used).</td></tr>
<tr><td>Skills</td><td colspan="8">Skilled personnel essential to operate vacuum sweeping equipment.</td></tr>
<tr><td>Safety precautions</td><td colspan="8">Respiratory protection may be required when using manually operated equipment in dry conditions. In highly contaminated areas, the tank containing the dust must be water-filled. It may even be recommended to apply a metal shielding between the operator and the waste vessel.</td></tr>
<tr><td colspan="9">Waste</td></tr>
<tr><td>Amount</td><td colspan="8">1 10^{-1} – 2 10^{-1} kg m^{-2}. The amount depends on dustiness of surface. If cleaning done under wet conditions and water disposed of directly to drains, then the waste will be higher).</td></tr>
<tr><td>Type</td><td colspan="8">Dust and sludge.</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td rowspan="5">Averted doses</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239 (% reduction in resuspension dose)</td></tr>
<tr><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td><5</td><td>5-10</td><td><5</td><td>5-10</td><td>0</td><td>5-10</td><td><5</td><td>5-10</td></tr>
<tr><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Consistency in effective implementation of option over a large area.
Population behaviour in area.
Amount of hard outdoor surfaces in the area i.e. environment type/land use.
Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Whether decontamination is carried out on adjacent paved surfaces.
Run-off of contamination onto other outdoor surfaces.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of plume activity (if radionuclide release is ongoing)
• inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)
• Inhalation of dust generated
• *Inadvertent ingestion of dust from workers' hands*
Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE.
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td rowspan="2">Operator time</td><td colspan="2">Work rate (m^2/team.hr)</td><td colspan="6">3 10^3 – 2 10^4. Depends on the equipment used</td></tr>
<tr><td colspan="2">Team size (people)</td><td colspan="6">1</td></tr>
<tr><td>Factors influencing costs</td><td colspan="8">weather,
topography,
size of area to be treated,
type of equipment used,
access</td></tr>
<tr><td colspan="9">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="8">Vacuum sweeping in wet conditions will create contaminated waste water, which may be disposed directly to drains or filtered prior to disposal.
The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.</td></tr>
<tr><td>Social impact</td><td colspan="8">Acceptability of active disposal of contaminated waste water into the public sewer system
Acceptability of disposal of filtered waste from contaminated water.
Vacuum sweeping of roads and pavements will make an area look clean; implementation may give public reassurance.</td></tr>
<tr><td>Practical experience</td><td colspan="8">Applied in the Former Soviet Union after the Chernobyl accident. Small-scale tests conducted in Denmark and USA under varying conditions to examine the influence of e.g. street dust loading.</td></tr>
<tr><td>Key references</td><td colspan="8">Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for</td></tr>
</table>

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	Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, **46**, (2), 207-223. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Calvert S, Brattin H and Bhutra S (1984). *Improved street sweepers for controlling urban particulate matter.* A.P.T. Inc., 4901 Morena Blvd., Suite 402, San Diego, CA 97117, EPA-600/7-84-021. Roed J (1990). *Deposition and removal of radioactive substances in an urban area.* Final report of the NKA Project AKTU-245, Nordic Liaison Committee for Atomic Energy, ISBN 87-7303-514-9. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p.
Version	2
Document history	See Table 3.2.

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35 Cover grassed and soil surfaces (e.g. with asphalt)

Objective	To reduce inhalation and external gamma and beta doses from contamination in outdoor areas covered in grass or soil within inhabited areas.
Other benefits	None
Management option description	A layer of asphalt (or alternatives, e.g. concrete or paving stones) can be applied over small areas adjacent to buildings. This measure will provide shielding from contamination on the ground area. It is likely to be considered for reducing external exposure from residual contamination after removing a topsoil layer, as soil very close to a building may, in some cases, be contaminated to a greater depth, due to run-off from the building. Generally, the procedure would involve applying a layer of stabilising gravel, then asphalt (using shovels and other hand-tools) and finally to use a roller to consolidate. Resurfacing using asphalt may also be carried out by applying a thick layer of gravel, onto which is sprayed a thin sealing asphalt emulsion layer, and finishing with a thin layer of gravel. Dust creation during implementation is unlikely to be a problem therefore management options to reduce resuspension hazard to workers will not be necessary (unless the resuspension hazard in the area is deemed significant). This option severely complicates subsequent removal of the contamination.
Target	Soil (and grassed) areas and other small to medium sized open areas. Targeted areas are typically around residential buildings, schools etc, where people generally spend much of their time while outdoors.
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides alone.
Scale of application	Small - medium sized areas with boundaries around buildings.
Time of application	Maximum effectiveness will be achieved for several years after contamination has occurred, as soil migration is typically slow. Will continue to be effective for many years after deposition has occurred. May be beneficial to wait until after first rain so that most dust has washed off other outdoor surfaces and buildings onto soil and grass areas.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Cultural heritage protection.
Environmental constraints	Cold weather (temperature must be > 5 °C). In extreme cases, the slope of the area may be a concern.
Effectiveness	
Reduction in contamination on the surface	The decontamination factor (DF) for this option is 1, as no contamination is removed.
Reduction in surface dose rates	While the asphalt remains undisturbed, the external gamma dose rate above the surface will be reduced by a factor which is dependent on the energy of the gamma rays emitted and the depth of the asphalt layer used. This option will effectively reduce external beta dose rates above the surface by 100 %.
Reduction in resuspension	Resuspended activity in air above the soil (or grass) surface will be effectively reduced to 100 %.
Technical factors influencing effectiveness	Evenness of underlying surface. Thickness of layer (typically 5 - 10 cm of asphalt). Size of treated area (large areas will have higher ‘surface’ dose rate reduction). Density of material used (for asphalt - dependent on type of pebbles - typically 1.6 g cm^{-3} - 2 g cm^{-3}). Traces of contamination in the cover material.
Social factors influencing effectiveness	None
Feasibility	
Equipment	Small asphalt roller. Shovels. Special rakes for planing gravel / asphalt layers. Trucks for transport of roller, asphalt and stabilising gravel.
Utilities and infrastructure	Roads for transport of asphalt (or concrete).
Consumables	Asphalt. Stabilising gravel. Fuel and parts for equipment and vehicles.
Skills	Skilled personnel essential to operate equipment.
Safety precautions	The usual precautions for asphalt workers:

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35 Cover grassed and soil surfaces (e.g. with asphalt)

	Safety helmets Gloves Safety shoes May also require respiratory protection, particularly in dry and dusty conditions.
Waste	
Amount and type	None
Doses	
Averted doses	Not estimated.
Factors influencing averted dose	Consistency in effective implementation of option over a large area. Population behaviour in area. Amount of grass/soil in the area i.e. environment type/land use. Size of the area resurfaced. Time of implementation. The impact on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)
Intervention costs	
Operator time	15 m^2/team.hr (team size: 4 people).
Factors influencing costs	Weather. Evenness of surface. Size of area to be resurfaced. Type of equipment used. Access. Use of personal protective equipment (PPE). Need to take into account drainage/sewerage pipes etc. Vegetation may need to be removed prior to resurfacing. Thickness of the asphalt layer used and the quality of the asphalt will affect the materials cost.
Side effects	
Environmental impact	Total loss of biodiversity in the treated area. Total loss of fertility in the treated area. Acceptability of smothering flora and fauna/change from soil to e.g. tarmac surface.
Social impact	Acceptability of leaving some contamination in-situ. Aesthetic consequences of landscape /amenity changes.
Practical experience	The method has been widely applied in the Former Soviet Union after the Chernobyl accident.
Key references	Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Gjørup H, Jensen NO, Hedemann Jensen P, Kristensen L, Nielson OJ, Petersen EL, Petersen T, Roed J, Thykier-Nielsen S, Heikel Vinther F, Warming L and Aarkrog A (1982). *Radioactive contamination of Danish terrirory after coremelt accidents at the Barsebäck power plant.* Risø National Laboratory, Risø-R-462. Hedemann Jensen P, Lundtang Petersen E, Thykier-Nielsen S and Heikel Vinther F (1977). Calculation of the individual and population doses on Danish terrirory resulting from hypothetical core-melt accidents at the Barsebäck reactor. Risø National Laboratory, Risø-R-356.
Version	2
Document history	See Table 3.2. Datasheet called ‘Resurfacing with eg. asphalt in frequently occupied areas’ in STRATEGY 2003.

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36 Cover with clean soil

Objective	To reduce inhalation and external gamma and beta doses from outdoor areas that are covered with grass and soil within inhabited areas.
Other benefits	Shielding of contamination with soil effectively ties-down the underlying contamination that could otherwise be resuspended. This is therefore an effective tie-down option.
Management option description	A 5 - 10 cm layer of radiologically clean soil can be applied in areas where people spend time to shield against contamination on the ground. May also be applied to reduce the external dose rate from residual contamination on a soil surface after removal of a topsoil layer. Also used for tie-down of contaminated soil to reduce the resuspension hazard to members of the public. This option severely complicates subsequent removal of the contamination.
Target	Grass/soil surfaces in gardens, parks, playing fields and other open spaces.
Targeted radionuclides	All radionuclides (via shielding). Can be used to reduce external doses from short-lived radionuclides if implemented quickly. Tie-down targets alpha emitting radionuclides that give rise to inhalation doses from resuspended material.
Scale of application	Any size.
Time of application	**Tie-down:** maximum benefit is achieved if carried out soon after deposition when most of the contamination remains on the ground surface and resuspension is likely to be high. **Shielding:** likely to be effective for a long time after deposition. Early implementation may mean that contamination that washes off other surfaces over time onto soil and grass re-contaminates clean soil, therefore reducing the effectiveness somewhat.
Constraints	
Legal constraints	Liabilities for possible damage to property. Listed and other historically important buildings (and gardens). Ownership and access to property. Use on listed or historic sites and in conservation areas.
Environmental constraints	Acceptability of smothering flora and fauna. Severe cold weather.
Effectiveness	
Reduction in contamination on the surface	This option has a decontamination factor (DF) of 1, since no contamination is removed. This option leaves contaminated material in-situ. Subsequent disturbance of the clean layer, by whatever means, will reduce the effectiveness of the option. For example, the land's topography may lead to uneven erosion of the 'clean' layer to re-expose the underlying contaminated material. A reduction in gamma dose-rate above the clean soil of 30-80% could be expected depending on the energy of the radionuclide. This option will be 100% effective in reducing external beta dose-rates (see section 4.6.2.3 for more information).
Reduction in surface dose rates	While the clean layer remains undisturbed, the external gamma dose rate above the surface will be reduced by a factor which is dependent on the energy of the gamma rays emitted and the depth of the clean soil layer used. Effectiveness in reducing dose-rates above the surface will be dependent on the size of the area treated and how well the procedure is implemented. This option will effectively reduce external beta dose rates above the surface by 100 %.
Reduction in resuspension	Resuspended activity in air above the soil surface will be reduced by close to 100 % while the soil remains in place.
Technical factors influencing effectiveness	Availability of required quantities of soil. Thickness of soil layer used. Size of treated area. Evenness of ground surface. Correct implementation of option. If done too early, more contamination washes onto clean soil. Number of plants, shrubs and trees left in area.
Social factors influencing effectiveness	Restrictions on digging the soil that has been used to cover contamination.
Feasibility	
Equipment	Spades. Bobcat mini-bulldozer. Rake. Transport vehicles for equipment and soil.
Utilities and infrastructure	Roads for transport of equipment and materials.

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36 Cover with clean soil

<table>
<tr><td>Consumables</td><td colspan="2">Soil.
Fuel and parts for bulldozer and transport vehicles.</td></tr>
<tr><td>Skills</td><td colspan="2">On a small scale, using spades, this option can be implemented by unskilled workers. This option could be implemented as a self-help measure. Instruction and provision of safety and other required equipment should be ensured. Requires hard physical work, which not all persons would be capable of.
Skilled workers will be required to operate bulldozers, which will be used for larger areas.</td></tr>
<tr><td>Safety precautions</td><td colspan="2">None</td></tr>
<tr><td colspan="3">Waste</td></tr>
<tr><td>Amount and type</td><td colspan="2">None.</td></tr>
<tr><td colspan="3">Doses</td></tr>
<tr><td>Averted doses</td><td colspan="2">Not estimated.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="2">Consistency in effective implementation of option over a large area.
Population behaviour in area.
Amount of grass/soil in the area ie environment type/land use.
Size of the area resurfaced.
Time of implementation. The impact on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.</td></tr>
<tr><td>Additional doses</td><td colspan="2">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)
• inhalation of dust generated
• <i>inadvertent ingestion of dust from workers' hands</i>
Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE.</td></tr>
<tr><td colspan="3">Intervention costs</td></tr>
<tr><td rowspan="3">Operator time</td><td>Small areas</td><td>Large areas</td></tr>
<tr><td>2 10¹ m² h⁻¹ per team
Team size: 1</td><td>4 10² m²/team.hr
Team size: 2</td></tr>
<tr><td colspan="2">Depends on access and openness of area and equipment used</td></tr>
<tr><td>Factors influencing costs</td><td colspan="2">Thickness of soil layer used.
Operator skill.
Soil type and condition.
Amount of vegetation to be removed.
Weather.
Topography.
Size of area.</td></tr>
<tr><td colspan="3">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="2">Possible adverse impact on bio-diversity.
Aesthetic consequences of landscape changes.
Loss of plants.
Possible soil erosion risk due to increased soil depth, although reseeding of grass or replanting would reduce the risk of soil erosion.</td></tr>
<tr><td>Social impact</td><td colspan="2">Adverse aesthetic effect of covering areas with bare earth.
Access to public areas may need to be restricted temporarily before clean soil is applied.
Loss of public amenity if used to cover grass areas.</td></tr>
<tr><td>Practical experience</td><td colspan="2">Tested intensively in the Former Soviet Union.</td></tr>
<tr><td>Key references</td><td colspan="2">Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). <i>Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.</i> Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark.
Fogh CL, Andersson KG, Barkovsky AN, Mishine AS, Ponamarjov AV, Ramzaev VP and Roed J (1999). Decontamination in a Russian settlement. <i>Health Physics</i>, 76, (4), 421-430.
Roed J, Andersson KG, Varkovsky AN, Fogh CL, Mishine AS, Olsen SK, Ponomarjov AV, Prip H, Ramzaev VP, Vorobiev VF (1998). <i>Mechanical decontamination tests in areas affected by the Chernobyl accident.</i> Risø-R-1029, Risø National Laboratory, Roskilde, Denmark.
Roed J, Lange C, Andersson KG, Prip H, Olsen S, Ramzaev VP, Ponomarjov AV,</td></tr>
</table>

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36 Cover with clean soil

	Varkovsky AN, Mishine AS, Vorobiev BF, Chesnokov AV, Potapov VN and Shcherbak SB (1996). *Decontamination in a Russian settlement.* Risø National Laboratory, Risø-R-870, ISBN 87-550-2152-2.
Version	2
Document history	See Table 3.2. Datasheet called 'Application of clean sand/soil around dwellings and in frequently occupied areas' in STRATEGY 2003.

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37 Deep ploughing

Objective	To reduce inhalation and external gamma and beta doses from contamination in outdoor areas covered in grass or soil within inhabited areas.
Other benefits	Deep ploughing may reduce contamination in the surface soil layer (reduction of 90 - 95 % of contamination in upper 20 cm of soil) in which food may subsequently be grown and so reduce uptake into food crops.
Management option description	Deep ploughing with a standard single-furrow mouldboard plough to a depth of 450 mm effectively buries contamination in the top few cms of the soil and also mixes contamination throughout the ploughed depth of soil. Deep ploughing removes most of the contamination from the root uptake zone of plants. A special deep plough that tills the soil to a depth of 900 mm may also be available. Such ploughs require a more powerful tractor than is commonly available. Removal of plants, shrubs and trees may be necessary before ploughing. Afterwards, replanting, replacing grass and fertilising and rolling the land may be required. The mixing of contamination by deep ploughing is irreversible and will severely complicate subsequent removal of contamination. This option is likely to give rise to dust, so application of water to dampen the surface or the use of a tie-down material is recommended prior to implementation to limit the resuspension hazard (Datasheet 44). Deep ploughing must not be repeated, as this could bring contamination back to the surface.
Target	Grass and soil surfaces in large, parks, playing fields and other open spaces, which have not been tilled since deposition occurred.
Targeted radionuclides	All radionuclides. Short-lived radionuclides if implemented quickly.
Scale of application	Suitable for large surface areas only (e.g. parks).
Time of application	Maximum benefit is obtained if implemented soon after deposition. However, it will continue to be significantly effective for many years after deposition because contamination will remain in the top 5 cm for many years. The effectiveness will gradually decrease with time.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use on listed and historic sites or in conservation areas.
Environmental constraints	Severe cold weather. Soil texture (must not be too loose / sandy). In extreme cases, the slope of the area maybe a constraint. Soil depth of greater than 45 cm is required for deep ploughing. High ground water level.
Effectiveness	
Reduction in contamination on the surface	This option has a decontamination factor (DF) of 1 because it removes no contamination.
Reduction in surface dose rates	External gamma dose rates above the surface will be reduced by a factor of between 5 and 10 for medium to high energy gamma emitters. Reductions in dose rate will depend on: radionuclides involved ploughing depth soil contamination profile with depth at the time of implementation success of the implementation Beta dose rate reduction is likely to be significantly higher than the values given above if the technique is implemented effectively.
Reduction in resuspension	By effectively burying most of the contamination, resuspended activity in air above the surface will be reduced by a factor significantly larger than the external gamma dose rate reduction.
Technical factors influencing effectiveness	Weather conditions. Correct implementation of option. Soil texture. Whether area has been tilled since deposition. Time of implementation: if contamination has migrated below the ploughing depth, the technique will be much less effective. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness.
Social factors influencing effectiveness	None
Feasibility	

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37 Deep ploughing

<table>
<tr><td>Equipment</td><td colspan="8">Deep plough.
Tractor powerful enough to pull a deep plough.
Transport vehicles for equipment.</td></tr>
<tr><td>Utilities and infrastructure</td><td colspan="8">Roads for transport of equipment.</td></tr>
<tr><td>Consumables</td><td colspan="8">Fuel and parts for transport vehicles and tractor. Fuel: around 15 litres ha^{-1} for ploughing.
Plants and replacement grass.</td></tr>
<tr><td>Skills</td><td colspan="8">Personnel skilled in ploughing can be used but must be instructed carefully about the objective.</td></tr>
<tr><td>Safety precautions</td><td colspan="8">Very dusty conditions: respiratory protection & protective clothes may be recommended to reduce the hazard from resuspended activity.</td></tr>
<tr><td colspan="9">Waste</td></tr>
<tr><td>Amount and type</td><td colspan="8">None</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td rowspan="5">Averted doses</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239 (% reduction in resuspension dose)</td></tr>
<tr><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td>15-20</td><td>15-20</td><td>20-25</td><td>25-30</td><td><5</td><td>5-10</td><td>5-10</td><td>10-15</td></tr>
<tr><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Consistency in effective implementation of option over a large area.
Population behaviour in area.
Amount of grass/soil in the area i.e. environment type/land use.
Time of implementation. The impact of ploughing on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Whether recovery options have been applied to other nearby ground surfaces.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of radioactive material resuspended from the ground and other surfaces
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td>Operator time</td><td colspan="8">7 10^{3} m^{2}/team.hr (team size: 1 person).</td></tr>
<tr><td>Factors influencing costs</td><td colspan="8">Soil type and condition.
Amount of vegetation.
Weather.
Use of personal protective equipment (PPE).
Topography.
Size of area.
Evenness of ground surface.
Access.
Need to replant.</td></tr>
<tr><td colspan="9">**Side effects**</td></tr>
<tr><td>Environmental impact</td><td colspan="8">Soil erosion risk (may be reduced by reseeding of grass).
May bring contamination closer to groundwater.
Acceptability of smothering flora and fauna and loss of plants and shrubs.
Loss of soil fertility.
Severely complicates subsequent removal of contamination.
Soil may need to be rolled afterwards before use.</td></tr>
<tr><td>Social impact</td><td colspan="8">Adverse aesthetic effect.
Loss of public amenity.
Leaving contamination in-situ.
Temporary restriction of access to public areas.
Restrictions on subsequent tilling of the land may not be practicable or acceptable.</td></tr>
<tr><td>Practical experience</td><td colspan="8">Tested widely in the Former Soviet Union and on limited scale in Denmark.</td></tr>
<tr><td>Key references</td><td colspan="8">Andersson KG, Rantavaara A, Roed J, Rosén K, Salbu B and Skipperud L (2000). *A guide to countermeasures for implementation in the event of a nuclear accident affecting Nordic food-producing areas.* NKS/BOK 1.4 project report NKS-16, ISBN 87-7893-066-9, 76p.
Brown J and Jones AL (2000). Review of decontamination and remediation techniques for</td></tr>
</table>

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37 Deep ploughing

	plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). *Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p. Vovk IF, Blagoyev VV, Lyashenko AN and Kovalev IS (1993). Technical approaches to decontamiantion of terrestrial environments in the CIS (former USSR). *Science of the Total Environment*, **137**, 49-64.
Version	2
Document history	See Table 3.2.

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38 Grass cutting & removal

Objective	To reduce inhalation and external beta and gamma doses from contamination on outdoor grassed areas within inhabited areas.
Other benefits	Removal of contamination from grassed areas. Prevention of contamination reaching underlying soil if deposition occurred under dry conditions.
Management option description	Grass area is mown and grass cuttings are collected. The grass cutting height should be as low as possible. This option is likely to give rise to dust. It will not be possible to apply water to dampen the surface without moving contamination from the grass onto the underlying soil, thereby jeopardising the objective of the grass cutting. The use of personal protective equipment by workers is therefore recommended to limit the resuspension hazard.
Target	Grass surfaces in gardens, parks, playing fields and other open spaces.
Targeted radionuclides	All radionuclides. Short-lived radionuclides if implemented quickly.
Scale of application	Any size.
Time of application	Maximum benefit if carried out within 1 week of deposition when maximum contamination is on grass. Effectiveness is significantly reduced after rain has occurred or if grass has already been cut post deposition.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Waste disposal of collected grass cuttings.
Environmental constraints	Severe cold weather (snow and ice) or if the weather is very dry and grass has not grown.
Effectiveness	
Reduction in contamination on the surface	Decontamination factor (DF) between 2 and 10 can be achieved if this option is implemented within one week of deposition and before significant rain occurs.
Reduction in surface dose rates	External gamma and beta dose rates immediately above grass surfaces will be reduced by approximately the value of the DF.
Reduction in resuspension	Resuspended activity in air immediately above a grass surface will be reduced by approximately the value of the DF.
Technical factors influencing effectiveness	Weather conditions, particularly those at the time of deposition, and the amount of rain post deposition. Correct implementation of option (all grass cuttings must be collected to achieve the DF values quoted). Time of operation (the longer the time between deposition and implementation of the option, the less effective the technique will be). Evenness of ground surface. Length of the grass at time of deposition. Consistency in effective implementation of option over a large area. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Grass mowers (various sizes, depending on size of area), preferably fitted with collection boxes to ensure total collection of grass cuttings. A tractor may be required for large areas. Rakes or other collection equipment if grass cutting equipment is not equipped with collection boxes. Transport vehicles for equipment and waste.
Utilities and infrastructure	Roads for transport of equipment and waste.
Consumables	Fuel and parts for grass mowers and vehicles.
Skills	Skilled personnel may be desirable if large scale equipment is used, i.e. for larger area grass mowing. For small gardens, grass cutting could be implemented by land owners as a self-help measure with instruction from authorities and provision of safety equipment.
Safety precautions	Respiratory protection and protective clothes/gloves may be recommended to reduce the hazard from resuspended activity, particularly under very dry conditions.
Waste	
Amount and type	Amount: $1\ 10^{-4} – 7\ 10^{-4}\ m^3\ m^{-2}$ ($<150\ g\ m^{-2}$) (depends on height of grass cut and density of grass cover). Type: Grass. It is noted that waste amounts generated can be large. However methods exist which can

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38 Grass cutting & removal

<table>
<tr><td></td><td colspan="8">substantially reduce the volume of organic waste by up to a factor of about 100. Some of these methods (e.g. composting) could be practised locally and could be very significant in reducing any waste transport and storage problems.</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td rowspan="5">Averted doses</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239 (% reduction in resuspension dose)</td></tr>
<tr><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td>20-25</td><td>10-15</td><td>25-30</td><td>15-20</td><td>5-10</td><td>5-10</td><td>10-15</td><td>10-15</td></tr>
<tr><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Consistency in effective implementation of option over a large area.
Reductions in external and resuspension doses received by a member of public living in the area will depend on the amount of the area covered by grass and the time spent by individuals on or close to grassed areas.
Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Whether adjacent soil surfaces are also decontaminated.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of plume activity (if radionuclide release is ongoing)
• inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td>Operator time</td><td colspan="8">2 10^2 – 1 10^4 m^2/team.hr depending on scale of equipment used.
Team size: 1 person.</td></tr>
<tr><td>Factors influencing costs</td><td colspan="8">Weather.
Topography.
Size of area.
Type of equipment used and whether grass has to be collected manually.
Access.
Use of personal protective equipment (PPE).</td></tr>
<tr><td colspan="9">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="8">The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.</td></tr>
<tr><td>Social impact</td><td colspan="8">Mowing grass can make an area look ‘tidy’.
Implementation may give public reassurance.
Access to public areas may need to be restricted temporarily before grass mowing is implemented.
Waste disposal may not be acceptable.</td></tr>
<tr><td>Practical experience</td><td colspan="8">Tested on a small scale in Europe.</td></tr>
<tr><td>Key references</td><td colspan="8">Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2.
Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). <i>Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.</i> Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark.
Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. <i>Journal of Environmental Radioactivity</i>, 46, (2), 207-223.
Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315.
Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR.
Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). <i>Strategies of decontamination.</i> Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3.</td></tr>
</table>

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	38 Grass cutting & removal
	Maubert H, Vovk I, Roed J, Arapis G and Jouve A (1993). Reduction of soil-plant transfer factors: mechanical aspects. *Science of the total Environment*, **137**, 163-167. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p.
Version	2
Document history	See Table 3.2. Called 'Lawn mowing' in STRATEGY 2003.

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39 Manual digging

Objective	To reduce inhalation and external gamma and beta doses from contamination in outdoor areas covered in grass or soil within inhabited areas.
Other benefits	None
Management option description	Most of the initial deposition remains in the top 50 mm of soil for many years (certainly the case for clay and brown earth soils). Therefore, if the top layers of soil are dug to a depth of about 15 - 30 cm and it is attempted to bury the top layer of soil or turf to the bottom of this vertical profile, a significant shielding from the contamination can be obtained. Double digging, in which the top 150 mm of soil is inverted, can also be carried out. This is a traditional method for digging vegetable gardens, particularly for potato crops. The top spade depth of soil is removed; the second spade depth is broken up, effectively mixing the soil to improve it. The top layer is then inverted and replaced. If the area is covered with turf, the top layer should be placed turf down if possible. The mixing of contamination by digging is irreversible and will severely complicate subsequent removal of contamination. Large plants and shrubs may need to be removed before digging. Other digging methods may be more suitable and are described in Datasheet 42 (rotovating) and Datasheet 47 (triple digging). In dry conditions, this option may give rise to dust, so application of water to dampen the surface is recommended prior to implementation to limit the resuspension hazard in these conditions (see Datasheet 44). The method must not be repeated, as this could bring contamination back to the surface.
Target	Grass and soil surfaces in gardens, and other small open spaces. This option is not appropriate for areas that have already been tilled since deposition occurred.
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides.
Scale of application	Suitable for small soil/grass areas only (e.g. gardens).
Time of application	Maximum effectiveness will be achieved for several years after contamination has occurred, as most contaminants migrate only very slowly down the soil profile. Will continue to be effective up to 10 year after deposition, although effectiveness will reduce with time.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use on listed or historic sites and conservation areas.
Environmental constraints	If the ground is snow-covered or frozen down to the digging depth, this method is not practicable. Soil texture. In extreme cases, the slope of the area maybe a constraint.
Effectiveness	
Reduction in contamination on the surface	This option has a DF of 1 as no contamination is removed. A RRF of 100 can be achieved.
Reduction in surface dose rates	External gamma dose rates above the surface could be reduced by up to 80% depending on the soil contamination profile with depth at the time of implementation and the success of implementation. External beta dose rates should be negligible.
Reduction in resuspension	By effectively burying activity, resuspended concentrations in air above a grass surface will be reduced by the value of the RRF.
Technical factors influencing effectiveness	Soil conditions: a very dry or loose consistency may make digging ineffective. Correct implementation of option: all the surface contamination must be buried to achieve the quoted resuspension reduction. Consistency of application. Soil texture (does the soil contain stones? etc.). Size of area. Larger dose rate reductions seen if a large area is dug. Any previous tilling since deposition. Time of implementation. If contamination has migrated below the top 15 cm, technique will be less effective.
Social factors influencing effectiveness	None
Feasibility	
Equipment	Spade. Transport vehicles for equipment.
Utilities and infrastructure	Roads for transport of equipment.
Consumables	Fuel and parts for transport vehicles.
Skills	Only a little instruction is likely to be required. This option could, to some extent, be

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39 Manual digging

<table>
<tr><td></td><td colspan="8">implemented by inhabitants of the affected area as a self-help measure, after instruction from authorities and provision of safety and other required equipment. However, digging is a strenuous activity and people would need to be fit.</td></tr>
<tr><td>Safety precautions</td><td colspan="8">Under very dusty conditions respiratory protection and protective clothes/gloves may be recommended to reduce the hazard from resuspended activity.</td></tr>
<tr><td colspan="9">Waste</td></tr>
<tr><td>Amount and type</td><td colspan="8">None</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td>Averted doses</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239(% reduction in resuspension dose)</td></tr>
<tr><td></td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td></td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td></td><td>20-25</td><td>25-30</td><td>25-30</td><td>35-40</td><td>5-10</td><td>10-15</td><td>10-15</td><td>20-25</td></tr>
<tr><td></td><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Effective implementation of option over a large area.
Reductions in external and resuspension doses received by a member of public living in the area will depend on the amount of the area covered by grass and the time spent by individuals on or close to grassed areas.
Time of implementation. The impact of double digging on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
If only soil areas are dug, need to consider other options for grass areas.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) Inhalation of dust generated
• *inadvertent ingestion of dust from workers' hands*
Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td>Operator time</td><td colspan="8">4 – 6 m^2/team.hr (team size: 1 person).</td></tr>
<tr><td>Factors influencing costs</td><td colspan="8">Soil type and condition.
Weather.
Topography.
Evenness of ground surface and level of vegetation.
Access to gardens and other areas.
Use of personal protective equipment (PPE).
Fitness of workers (heavy manual task).</td></tr>
<tr><td colspan="9">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="8">Soil erosion risk (reseeding would reduce this).
May reduce soil fertility.
Possible partial loss of biodiversity.
May bring contamination closer to groundwater.
Severely complicates subsequent removal of contamination as more waste will be generated and mixing will make segregation of contaminated waste more difficult.</td></tr>
<tr><td>Social impact</td><td colspan="8">Adverse aesthetic effect of digging gardens (non-soil areas).
Destruction of gardens and loss of plants leading to temporary loss of garden function.
Contamination is not removed.
Restriction of some future gardening activities may be optimal.</td></tr>
<tr><td>Practical experience</td><td colspan="8">The method has been tested on a small scale in Europe.</td></tr>
<tr><td>Key references</td><td colspan="8">Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark.
Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315.
Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR.
Roed J (1990). *Deposition and removal of radioactive substances in an urban area.* Final report of the NKA Project AKTU-245, Nordic Liaison Committee for Atomic Energy, ISBN 87-7303-514-9.</td></tr>
</table>

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39 Manual digging	
	Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p.
Version	2
Document history	See Table 3.2. Datasheet called 'Garden digging' in STRATEGY 2003.

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40 Plant and shrub removal

Objective	To reduce inhalation and external gamma and beta doses from contamination in outdoor areas that contain shrubs or plants within inhabited areas.
Other benefits	Removal of contamination from vegetated areas. Removal of activity in gardens may reduce subsequent contamination of soil used for growing food. This in turn may reduce up-take to food crops grown.
Management option description	A portable brush cutter or forage harvester (depending on the size of the area being treated) is used to remove plant growth. Waste vegetation is removed by loading into trailers. Replanting is likely to be required. For maximum benefit, this should be considered with other options to decontaminate grass areas. Likely to give rise to dust. It will not be possible to apply water to dampen the surface without moving contamination from the plant onto the underlying soil. The use of PPE by workers is therefore recommended to limit the resuspension hazard.
Target	Plant and shrubs in gardens, parks, playing fields and other open spaces.
Targeted radionuclides	All radionuclides. Short-lived radionuclides if implemented quickly.
Scale of application	Any size.
Time of application	Maximum benefit if carried out within 1 week of deposition when maximum contamination is on the plants and shrubs. Effectiveness is significantly reduced after rain has occurred. Unlikely to be needed in autumn/winter when much foliage has died.
Constraints	
Legal constraints	Liabilities for possible damage to property. Listed and other historically important sites and conservation areas. Ownership and access to property. Waste disposal of collected vegetation.
Environmental constraints	Severe cold weather. Soil type and texture.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of between 2-10 and a resuspension reduction factor (RRF) of 10 can be achieved if this option is implemented within one week of deposition and before significant rain. Reductions in external and resuspension doses received by a member of public living in the area will depend on the amount of the area covered by plants and shrubs and the time spent by individuals on or close to these areas (see below).
Reduction in surface dose rates	External gamma and beta dose rates in an area containing plants and shrubs will be reduced by the value of the DF.
Reduction in resuspension	Resuspension in an area containing plants and shrubs may be reduced but this will be less than the value of the DF because of contamination on the surrounding soil.
Technical factors influencing effectiveness	Weather particularly those at the time of deposition, and the amount of rain post deposition. Correct implementation of option – all material must be collected to achieve the DF value quoted. Time of operation (contamination migrates into the soil over time). Consistency in effective implementation of option over a large area. Amount of plants and shrubs in the area. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Whether adjacent surfaces, e.g. grass areas are also decontaminated. Whether recovery options have been applied to adjacent ground surfaces.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Brush cutter. Tractor. Trailer. Brushwood chipper. A forage harvester may be required for larger areas. Transport vehicles for equipment and waste.
Utilities and infrastructure	Roads for transport of equipment and waste.
Consumables	Fuel and parts for tractors and harvesters.
Skills	Skilled personnel are required to operate brush cutters and forage harvesters.
Safety precautions	Respiratory protection and protective clothing.

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40 Plant and shrub removal

<table>
<tr><td></td><td colspan="8">Facial protection including safety goggles will be required when using brush cutters.</td></tr>
<tr><td colspan="9">Waste</td></tr>
<tr><td>Amount and type</td><td colspan="8">*Amount:* 2 kg m^{-2}.
Type: Vegetation and shrubby material.</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td>Averted doses</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239 (% reduction in resuspension dose)</td></tr>
<tr><td></td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td></td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td></td><td>10-15</td><td>10-15</td><td>10-15</td><td>15-20</td><td><5</td><td>10-15</td><td>5-10</td><td>10-15</td></tr>
<tr><td></td><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Consistency in effective implementation of option over a large area.
Population behaviour in area.
Amount of grass in the area i.e. environment type/land use.
Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Whether adjacent grass surfaces are also decontaminated.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of plume activity (if radionuclide release is ongoing)
• inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)
• inhalation of dust generated
• *inadvertent ingestion of dust from workers' hands*
Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE.
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td>Operator time</td><td colspan="8">1 $10^2 – 10^3$ m^2/team.hr (depends on equipment used and size of area).
Team size: 2 people.</td></tr>
<tr><td>Factors influencing costs</td><td colspan="8">Weather.
Topography.
Size of area.
Type of equipment used.
Access.
Height of vegetation.</td></tr>
<tr><td colspan="9">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="8">Possible adverse impact on bio-diversity.
Loss of plants and shrubs.
Disposal or storage of waste. However, this issue may be minimised through the control of any disposal route and relevant authorisations.</td></tr>
<tr><td>Social impact</td><td colspan="8">Adverse aesthetic effect of removing all plants & shrubs from parks or gardens.
Restricted access to public areas before implementation.
Waste disposal may not be acceptable.</td></tr>
<tr><td>Practical experience</td><td colspan="8">Tested on a semi-large scale in the Former Soviet Union after the Chernobyl accident.</td></tr>
<tr><td>Key references</td><td colspan="8">Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark.
Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315.
Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR.
Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840,</td></tr>
</table>

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40 Plant and shrub removal

	82p.
Version	2
Document history	See Table 3.2.

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41 Ploughing

Objective	To reduce inhalation and external gamma and beta doses from contamination in outdoor areas covered in grass or soil within inhabited areas.
Other benefits	None
Management option description	A standard mouldboard plough tills the soil to a depth of typically 25 – 30 cm, thereby mixing any contamination throughout the ploughed depth of soil. A significant amount of the contamination in the top few cms of soil is effectively buried. Special deep ploughs may also be used (see Datasheet 37). Removal of plants, shrubs and trees may be necessary before ploughing. Afterwards, replanting, replacing grass, rolling and fertilising the land may be required. The mixing of contamination by shallow ploughing is irreversible and will severely complicate subsequent removal of contamination. This option is likely to give rise to dust, so the application of water to dampen the surface, or the use of a tie-down material is recommended prior to implementation to limit the resuspension hazard. Further details are given in Datasheet 44. Ploughing must not be repeated, as this could bring contamination back to the surface.
Target	Grass and soil surfaces in large parks, playing fields and other open spaces, which have not been tilled since deposition occurred.
Targeted radionuclides	All radionuclides. Short-lived radionuclides if implemented quickly.
Scale of application	Suitable for large surface areas only (e.g. parks).
Time of application	Maximum benefit is obtained if ploughing is carried out soon after deposition, i.e. before soil migration occurs. However, it will continue to be significantly effective for many years after deposition has occurred because in most cases, the contamination will remain in the top 5 cm for many years (this is certainly the case for caesium in clay and brown earth soils). The effectiveness will gradually decrease with time.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use on listed and historic sites or in conservation areas.
Environmental constraints	Severe cold weather. Soil texture (must not be too loose / sandy). In extreme cases, the slope of the area maybe a constraint. Soil depth of > 0.3 m is required for shallow ploughing.
Effectiveness	
Reduction in contamination on the surface	This option has a decontamination factor (DF) of 1 because it removes no contamination.
Reduction in surface dose rates	External gamma and beta dose rates above the surface are likely to be reduced by 50-85%, depending on the ploughing depth and success of implementation. The reductions in dose rate will depend on the radionuclides involved, i.e. their gamma energies. The reduction will also depend on the ploughing depth and the soil contamination profile with depth at the time of implementation and the success of the implementation. Beta dose rate reduction is likely to be significantly higher than the values given above if the technique is implemented effectively.
Reduction in resuspension	By effectively burying most of the contamination, resuspended activity in air above the surface will be reduced by a resuspension reduction factor (RRF) of 100.
Technical factors influencing effectiveness	Weather. Correct implementation of option. Soil texture (does the soil contain stones etc.). Whether the area has been tilled since deposition. Time of implementation. If contamination has migrated below the ploughing depth, the technique will be much less effective. Consistency in effective implementation of option over a large area. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Whether recovery options have been applied to other nearby ground surfaces.
Social factors influencing effectiveness	None
Feasibility	
Equipment	Plough and tractor. Transport vehicles for equipment.
Utilities and infrastructure	Roads for transport of equipment.
Consumables	Fuel and parts for transport vehicles and tractor.

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41 Ploughing

<table>
<tr><td></td><td colspan="8">Plants and replacement grass.</td></tr>
<tr><td>Skills</td><td colspan="8">Personnel skilled in ploughing can be used but must be instructed carefully about the objective.</td></tr>
<tr><td>Safety precautions</td><td colspan="8">Under very dusty conditions respiratory protection and protective clothes may be recommended to reduce the hazard from resuspended activity.</td></tr>
<tr><td colspan="9">Waste</td></tr>
<tr><td>Amount and type</td><td colspan="8">None</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td rowspan="5">Averted doses</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239 (% reduction in resuspension dose</td></tr>
<tr><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td>10-15</td><td>15-20</td><td>15-20</td><td>20-25</td><td><5</td><td>10-15</td><td>5-10</td><td>15-20</td></tr>
<tr><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Consistency in effective implementation of option over a large area.
Population behaviour in area.
Amount of grass/soil in the area ie environment type/land use.
Time of implementation. The impact of ploughing on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) (can be controlled with the use of air-conditioned tractors)
• inhalation of dust generated
• *inadvertent ingestion of dust from workers' hands*
Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE.
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td>Operator time</td><td colspan="8">6 10^3 – 8 10^3 m^2/team.hr (team size: 1 person).</td></tr>
<tr><td>Factors influencing cost</td><td colspan="8">Soil type and condition.
Amount of vegetation.
Weather.
Use of personal protective equipment.
Topography.
Size of area.
Evenness of ground surface.
Access.
Need to replant.</td></tr>
<tr><td colspan="9">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="8">Soil erosion risk (reduced by subsequent grass re-seeding).
Bring contamination closer to groundwater.
Loss of soil fertility.
Acceptability of smothering flora and fauna and loss of plants and shrubs.
Severely complicates subsequent removal of contamination.
Soil may need to be rolled afterwards before use.</td></tr>
<tr><td>Social impact</td><td colspan="8">Adverse aesthetic effect.
Loss of public amenity.
Leaving contamination in-situ.
Access to public areas may need to be restricted temporarily before ploughing is implemented.
Restriction on subsequent tilling of the land may not be practicable or acceptable.</td></tr>
<tr><td>Practical experience</td><td colspan="8">Tested widely in the Former Soviet Union and on limited scale in Denmark.</td></tr>
<tr><td>Key references</td><td colspan="8">Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark.
Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in</td></tr>
</table>

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41 Ploughing

	radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, **46**, (2), 207-223. Andersson KG, Rantavaara A, Roed J, Rosén K, Salbu B and Skipperud L (2000). *A guide to countermeasures for implementation in the event of a nuclear accident affecting Nordic food-producing areas.* NKS/BOK 1.4 project report NKS-16, ISBN 87-7893-066-9, 76p. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). *Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p. Vovk IF, Blagoyev VV, Lyashenko AN and Kovalev IS (1993). Technical approaches to decontamiantion of terrestrial environments in the CIS (former USSR). *Science of the Total Environment*, **137**, 49-64.
Version	2
Document history	See Table 3.2. Datasheet called 'Shallow ploughing (park areas) in STRATEGY 2003.

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42 Rotovating (mechanical digging)

Objective	To reduce inhalation and external gamma and beta doses from contaminated outdoor areas covered by grass or soil in inhabited areas.
Other benefits	If applied to vegetable plots, rotovating may reduce contamination in the soil depth used for growing crops due to the redistribution of contamination. This in turn may reduce uptake of radionuclides from the soil to food crops grown.
Management option description	Soil and grass areas are tilled using power driven machines (rotovators) under manual control. The machines till to a depth of about 150 mm. Rotovating mixes the upper soil layers fairly uniformly within a relatively shallow depth. The mixing of contamination by rotovating is irreversible and will severely complicate subsequent removal of contamination. Large plants and shrubs may need to be removed before rotovating and the area may need to be subsequently replanted and reseeded with grass or re-turfed. In dry conditions, this option may give rise to dust, and so tie-down with water may be wise. Other digging methods may be more suitable and are described in Datasheet 39 (manual digging) and Datasheet 47 (triple digging). Repeated rotovating will lead to a more uniform mixing of the contamination which will reduce the effectiveness of the option as less of the surface contamination will remain buried. This is not recommended.
Target	Grassed and soil surfaces.
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides.
Scale of application	Suitable for small surface areas only (e.g. gardens).
Time of application	Maximum effectiveness will be achieved for several years after deposition has occurred since most contaminants migrate only very slowly down the soil profile. Will continue to be effective up to about 10 years after initial deposition with reduced effectiveness over time.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use on listed and historic sites and conservation areas.
Environmental constraints	Severe cold weather. Soil texture. In extreme cases, the slope of the area maybe a constraint.
Effectiveness	
Reduction in contamination on the surface	This option has a decontamination factor (DF) of 1 as no contamination is removed.
Reduction in surface dose rates	External gamma and beta dose rates above the surface are likely to be reduced by by 50-70%, depending on the success of implementation. Dose rate reductions are likely to be less than those for manual digging since rotovation does not bury contamination under a clean soil layer but mixes (dilutes) it homogeneously over the treated depth.
Reduction in resuspension	Resuspended concentrations in air above a grass/soil surface will be reduced by a resuspension reduction factor (RRF) of 15 for implementation up to several years after deposition.
Technical factors influencing effectiveness	Weather: if soil is very dry, rotovation is likely to be less effective. Depth of rotovating. Soil texture (does the soil contain stones? etc.). Size of areas. Any previous tilling since deposition. Repeated tilling may bring more contamination back to the soil surface. Time of implementation: contamination may have migrated below the depth to which the rotovator can reach. Consistency in effective implementation of option over a large area. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Whether recovery options have been applied to other nearby ground surfaces.
Social factors influencing effectiveness	None
Feasibility	
Equipment	Rotovators. Transport vehicles for equipment.
Utilities and infrastructure	Roads for transport of equipment.

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42 Rotovating (mechanical digging)

<table>
<tr><td>Consumables</td><td colspan="8">Plants and turf / grass seed, as required.
Fuel and parts for transport vehicles and equipment.</td></tr>
<tr><td>Skills</td><td colspan="8">Skilled personnel are not essential to implement this option.</td></tr>
<tr><td>Safety precautions</td><td colspan="8">Under very dusty conditions, respiratory protection and protective clothes (PPE) may be recommended to reduce the hazard from resuspended radioactivity.</td></tr>
<tr><td colspan="9">Waste</td></tr>
<tr><td>Amount and type</td><td colspan="8">None</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td rowspan="5">Averted doses</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239 (% reduction in resuspension dose)</td></tr>
<tr><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td>10-15</td><td>15-20</td><td>10-15</td><td>20-25</td><td>5-10</td><td>20-25</td><td>10-15</td><td>25-30</td></tr>
<tr><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Consistency in effective implementation of option over a large area.
Population behaviour in area.
Amount of grass/soil in the area i.e. environment type/land use.
Time of implementation. The impact on the overall doses will be reduced with time as there will be less contamination on the surface due to natural weathering (soil migration is slow).</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)
• inhalation of dust generated
• *inadvertent ingestion of dust from workers' hands*
Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE.
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td>Operator time</td><td colspan="8">1 10^2 m^2/team.hr (team size: 1 person).</td></tr>
<tr><td>Factors influencing costs</td><td colspan="8">Soil type and condition.
Weather.
Topography.
Evenness of ground surface including stoniness.
Use of personal protective equipment (PPE).
Need to replant etc.</td></tr>
<tr><td colspan="9">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="8">Soil erosion risk (reseeding and replanting may minimise this).
Possible loss of soil fertility.
Destruction of plants.
Bringing contamination closer to groundwater.
Severely complicates subsequent removal of contamination as more waste will be generated and mixing will make segregation of contaminated waste more difficult.</td></tr>
<tr><td>Social impact</td><td colspan="8">Adverse aesthetic effect in gardens.
Destruction of garden and loss of plants leading to temporary loss of garden usage.
Contamination is not removed.
Restriction of some gardening activities (e.g. banning subsequent digging).</td></tr>
<tr><td>Practical experience</td><td colspan="8">None</td></tr>
<tr><td>Key references</td><td colspan="8">Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315.
Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR.</td></tr>
<tr><td>Version</td><td colspan="8">2</td></tr>
<tr><td>Document history</td><td colspan="8">See Table 3.2.</td></tr>
</table>

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43 Skim and burial ploughing

Objective	To reduce inhalation and external gamma and beta doses from contamination in outdoor areas covered in grass or soil within inhabited areas.
Other benefits	Reduction in the surface soil layer contamination (reduction of 90 – 95 % of contamination in upper 20 cm of soil) in which food may subsequently be grown and so reduce uptake into food crops.
Management option description	A specialist plough is used, with two ploughshares: a skim coulter and the main plough. The coulter skims off the upper 50 mm of soil and places it in the trench made by the main plough in the previous run. Simultaneously, the main plough digs a new trench and places the lifted subsoil on top of the thin layer of topsoil now in the bottom of previous trench. This results in the top 50 mm of soil being buried at 450 mm and the 50 - 450 mm layer not being inverted The effect on soil fertility is minimised, although it may be necessary to fertilise soil after implementation. The contamination is largely buried below the rooting zone for crops. Removal of plants, shrubs and trees may be necessary before ploughing. There may be a need to subsequently replant or replace grass. Rolling of the grass surface may be necessary prior to replanting or reseeding. This option is likely to give rise to dust, so application of water to dampen the surface or the use of a tie-down material is recommended prior to implementation to limit the resuspension hazard (Datasheet 44). Skim and burial ploughing must not be repeated, as this could bring contamination back to the surface.
Target	Grass and soil surfaces in large parks, playing fields and other open spaces, which have not been tilled since deposition occurred.
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides alone.
Scale of application	Suitable for large surface areas only (e.g. parks).
Time of application	Maximum benefit is obtained if ploughing is carried out soon after deposition (before soil migration occurs). However, it will continue to be effective for several years after deposition because in most cases, the contamination will remain in the top 5 cm for many years
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use on listed or historic sites and conservation areas.
Environmental constraints	Severe cold weather. Soil texture (not appropriate for sandy soils). In extreme cases, the slope of the area maybe a constraint. A soil depth of > 0.5 m is required.
Effectiveness	
Reduction in contamination on the surface	This option has a decontamination factor (DF) of 1 because no contamination is removed.
Reduction in surface dose rates	External gamma dose rates above the surface will be reduced by a factor of 10 and external beta dose rates should be stopped completely. The reductions in dose rate will depend on the radionuclides involved, i.e. their gamma energies. The reduction will also depend on the ploughing depth and the soil contamination profile with depth at the time of implementation and the success of the implementation. Beta dose rate reduction is likely to be 100%.
Reduction in resuspension	By effectively burying most of the contamination, resuspended activity in air above the surface will be reduced by a resuspension reduction factor (RRF) of 100.
Technical factors influencing effectiveness	Weather conditions. Correct implementation of option. Soil texture. Contamination profile in soil. Amount of the area covered by grass/soil. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Whether recovery options have been applied to other nearby ground surfaces.
Social factors influencing effectiveness	None
Feasibility	
Equipment	Skim and burial plough. Powerful tractor. Transport vehicles for equipment and waste. Skim and burial ploughing equipment is not readily available throughout Europe at the present time. As this procedure remains effective over several years, one piece of equipment could be used for a large area.

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43 Skim and burial ploughing

<table>
<tr><td>Utilities and infrastructure</td><td colspan="8">Roads for transport of equipment.</td></tr>
<tr><td>Consumables</td><td colspan="8">Fuel and parts for transport vehicles and equipment.</td></tr>
<tr><td>Skills</td><td colspan="8">Skilled ploughing personnel are essential to implement this option. They must be instructed carefully about the objective.</td></tr>
<tr><td>Safety precautions</td><td colspan="8">Very dusty conditions: respiratory protection & protective clothes (PPE) may be recommended to reduce the hazard from resuspended activity.</td></tr>
<tr><td colspan="9">Waste</td></tr>
<tr><td>Amount and type</td><td colspan="8">None</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td rowspan="5">Averted doses</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239 (% reduction in resuspension dose)</td></tr>
<tr><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td>15-20</td><td>15-20</td><td>20-25</td><td>25-30</td><td><5</td><td>5-10</td><td>5-10</td><td>10-15</td></tr>
<tr><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Consistency in effective implementation of option over a large area.
Population behaviour in area.
Amount of grass/soil in the area i.e. environment type/land use.
Time of implementation. The impact of ploughing on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) (can be controlled with the use of air-conditioned tractors)
• inhalation of dust generated
• *inadvertent ingestion of dust from workers' hands*
Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE.
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td>Operator time</td><td colspan="8">2 10^3 – 3 10^3 m^2/team.hr (team size: 1 person).</td></tr>
<tr><td>Factors influencing costs</td><td colspan="8">Soil type and condition.
Amount of vegetation.
Weather.
Topography.
Size of area.
Evenness of ground surface.
Access.
Operator skill.</td></tr>
<tr><td colspan="9">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="8">Soil erosion risk (reduced by re-seeding of grass).
This technique will bring contamination closer to groundwater.
Acceptability of smothering flora and fauna & loss of plants &shrubs.
Partial loss of soil fertility.
Severely complicates subsequent removal of contamination.
Land must not be deep ploughed in the future.
Soil may need to be rolled afterwards before use.</td></tr>
<tr><td>Social impact</td><td colspan="8">Adverse aesthetic effect.
Access to public areas may need to be restricted temporarily.
Leaving contamination in-situ.
Temporary loss of use of public amenity.</td></tr>
<tr><td>Practical experience</td><td colspan="8">Tested several times after Chernobyl in the Former Soviet Union and in Denmark in areas of size 1000 – 2000 m^2.</td></tr>
<tr><td>Key references</td><td colspan="8">Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark.
Andersson KG, Rantavaara A, Roed J, Rosén K, Salbu B and Skipperud L (2000). *A guide*</td></tr>
</table>

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43 Skim and burial ploughing

	to countermeasures for implementation in the event of a nuclear accident affecting Nordic food-producing areas. NKS/BOK 1.4 project report NKS-16, ISBN 87-7893-066-9, 76p. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). *Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. Roed J, Andersson KG and Prip H (1996). The skim and burial plough: a new implement for reclamation of radioactively contaminated land. *Journal of Environmental Radioactivity*, **33**, (2), 117-128. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p.
Version	2
Document history	See Table 3.2.

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44 Tie-down (fixing contamination to the surface)

Objective	To reduce inhalation doses from material resuspended from soil/grass areas within inhabited areas in the short term.
Other benefits	May be good for diluting the contamination. This may reduce external doses and, in the longer term, inhalation doses from resuspended material.
Management option description	Water, acrylic paint (Vinamul), or lignin (a non-toxic waste product from paper production) can be used for tie-down of contamination on grassed/soil surfaces. The procedure implemented is dependent on which substance is used and the size of the area being treated. **Water:** For small areas, the area is sprayed with water using a hose connected to a hydrant. For large areas, large hose reels rotated by a water turbine are used. As the reel winds in, a spraying boom is pulled towards the reel, propelling itself over the area. When one area is complete, it is towed by tractor to the next area. It should be noted that this management option should not be used if the aim is to tie contamination to grass prior to grass cutting, as the water will wash the contamination into the soil and root mat. **Acrylic paint:** For small areas, the area is sprayed with droplets 100 µm in diameter to ensure that radioactive particles adhere to the paint rather than being knocked off the surface. This is achieved by using a fine-mist spray gun with an airless pump. For large areas, the paint is applied by tractor-towed spray boom. **Lignin:** Lignin is sprayed onto the surface and mixes with the soil particles in a thin top layer of the soil (extent depends on water dilution and environmental moisture). Depending on the objective (long or short term tie-down) and the tie-down material used, repeated application may be necessary, to maintain the integrity of the cover.
Target	Grass surfaces in gardens, parks, playing fields and other open spaces.
Targeted radionuclides	Alpha emitting radionuclides that give rise to inhalation doses from resuspended material.
Scale of application	Any size.
Time of application	Any time after deposition; however, maximum benefit is achieved if carried out soon after deposition before penetration and fixing of the contamination in the soil has occurred. Tie-down is effective for the period over which the integrity of the covering is maintained. Effectiveness is reduced after rain has occurred.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use on conservation areas.
Environmental constraints	Severe cold weather, especially for tie-down with water.
Effectiveness	
Reduction in contamination on the surface	This option is not applied to decontaminate a surface, so the decontamination factor (DF) is 1. In practice, some contamination may be removed along with the tie-down material (if it is subsequently removed) and some activity may be washed onto other surfaces if water is used.
Reduction in surface dose rates	This option may be effective at reducing external beta dose rates above the surface while the tie-down remains intact, but is not effective at reducing external gamma dose rates.
Reduction in resuspension	Resuspended activity in air above the surface will be reduced by close to 100 % while the tie-down remains intact. Applying water will aid the bonding of activity to soil particles and can wash contamination below the surface, both of which will reduce resuspension in the longer term. However, if plants, shrubs and trees are not removed, these will still contribute to inhalation doses from resuspended material.
Technical factors influencing effectiveness	Weather conditions. Correct application of tie-down material over the contaminated area. Soil and grass surfaces must not be covered in snow. Length of grass (for lignin and paint): shorter grass is preferable to facilitate bonding.
Social factors influencing effectiveness	None
Feasibility	
Equipment	Depends on material used and the size of the area to be treated. **Water tie-down**: on small surface areas, a hydrant and hose are used. For large areas, a winding hose reel, pump and tractor with boom are used. **Paint tie-down:** on small surface areas, an airless spray pump and air compressor are used. For large areas, a tractor and boom are used. In all cases, transport vehicles for equipment are required.
Utilities and infrastructure	Roads (transport of equipment, materials and waste). Water supply.

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44 Tie-down (fixing contamination to the surface)

Consumables	Fuel and parts for transport vehicles. Water, acrylic paint (e.g. Vinamul), lignin.
Skills	Skilled personnel essential to operate equipment.
Safety precautions	Water-resistant clothing is recommended when using water. Additional protective clothing may be required when applying paint. Respiratory protective equipment (RPE) to protect against paint spray.
Waste	
Amount and type	None
Doses	
Averted doses	Not estimated. Tie-down will be 100% effective in reducing resuspension doses from the surface for the period that the tie-down material is in place as long as its integrity remains intact. Note that for water, this is likely to be only for a very short period.
Factors influencing averted dose	Consistency in effective implementation of option over a large area. Population behaviour in area. Amount of grass/soil in the area i.e. environment type/land use. Time of implementation. The impact on the overall doses will be reduced with time as there will be less contamination on the surface due to natural weathering (soil migration is slow). Length of time that the tie-down material is in place.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) • inhalation of dust generated • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included.
Intervention costs	
Operator time	$2\ 10^2 – 3\ 10^3\ m^2$/team.hr depending on tie-down material and equipment used. Team size: 2 people.
Factors influencing costs	Weather. Topography. Size of area. Type of equipment used. Access. Proximity of water supplies.
Side effects	
Environmental impact	Chemical contamination from acrylic paint (Vinamul) migrating into soil may be an issue. The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	Perception of contamination of the environment with chemicals.
Practical experience	Water and paint: none. **Lignin**: has been tested on a small scale (only a few m^2) in Denmark in conjunction with removal. Full scale tests on the use of lignin for dust suppression have been carried out in the USA and Sweden, where it is routinely used.
Key references	Andersson KG and Roed J (1994). The behaviour of Chernobyl ^{137}Cs, ^{134}Cs and ^{106}Ru in undisturbed soil: implications for external radiation. *Journal of Environmental Radioactivity*, 22, 183-196. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Dick JL and Baker TP (1961). Monitoring and decontamination techniques for plutonium fallout on large-area surfaces. Air Force Special Weapons Center, NT-1512. Tawil JJ and Bold FC (1983). *A Guide to Radiation Fixatives*. Pacific Northwest Laboratory, Richland, Nashington 99352, USA, PNL-4903, 1983.
Version	2

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44 Tie-down (fixing contamination to the surface)

Document history	See Table 3.2. This management option was considered in conjunction with soil removal in STRATEGY 2003 in datasheet called 'Topsoil removal applying lignin coating'.

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45 Top soil and turf removal (manual)

Objective	To reduce inhalation and external beta and gamma doses from contamination on outdoor grassed and soil areas within inhabited areas.
Other benefits	Removal of contamination from grassed and soil areas. Removal of activity from grass areas in gardens may reduce subsequent contamination of soil used for growing food. This in turn may reduce up-take to food crops grown.
Management option description	Turf and the top 50 mm of topsoil are removed using a spade. Any plants and shrubs may need to be removed first. Optionally, the soil can be replaced and can be reseeded or re-turfed depending on the size of the area. This option is likely to give rise to dust, so application of water to dampen the surface or the use of a tie-down material is recommended prior to implementation to limit the resuspension hazard if removal is implemented in the first few months following deposition (Datasheet 44). In the longer term, most of the contamination is attached to soil particles and is not in the respirable range.
Target	Grass surfaces in gardens, parks, playing fields and other small open spaces. Not recommended on land that has been tilled since the incident occurred. (Tilled areas can be treated but the waste volume will be much larger, as a greater depth of soil will have to be removed.)
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides alone.
Scale of application	Suitable for small areas (e.g. small gardens).
Time of application	Maximum effectiveness will be achieved for several years after deposition has occurred since most contaminants migrate very slowly down the soil profile.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Waste disposal of collected waste. Use on listed or historic sites and conservation areas.
Environmental constraints	Extreme cold weather. Soil texture. In extreme cases, the slope of the area may be a constraint.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of between 10 and 30 can be achieved if the removal depth is optimised soon after deposition. If a standard removal depth is used, the effectiveness will reduce in time after this as contamination migrates to deeper soil depths.
Reduction in surface dose rates	External gamma and beta dose rates above the soil surface will be reduced by the value of the DF.
Reduction in resuspension	Resuspended activity in air above the surface will be reduced by the DF.
Technical factors influencing effectiveness	Weather conditions, particularly those at the time of deposition, and the amount of rain after deposition. Correct implementation of option – all turf and soil must be collected to achieve the DF value quoted. Once contamination has migrated below 50 mm in depth the technique will start to become less effective unless the depth of removal is increased. This is likely to take several years after deposition. Soil texture: dry, crumbly soils will be more difficult to remove. Evenness of ground. Consistency in effective implementation of option. Amount of the area with grass/soil coverage. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Time of operation (contamination migrates into the soil over time). Whether recovery options have been applied to adjacent ground surfaces.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	(Depends on the size of the area being treated.) Spade. Seeding machine (if required). Transport vehicles for equipment and waste.
Utilities and infrastructure	Roads (transport of equipment, materials and waste).
Consumables	Fuel and parts for vehicles and equipment. Top soil.

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45 Top soil and turf removal (manual)

<table>
<tr><td></td><td colspan="8">Plants and turf or grass seed (if required).</td></tr>
<tr><td>Skills</td><td colspan="8">Only a little instruction is likely to be required. Care must be taken to remove soil to the optimal depth. This option could, to some extent, be implemented by inhabitants of the affected area as a self-help measure, after instruction from authorities and provision of safety and other required equipment.
It should be noted that this option requires hard physical work, which not all persons would be capable of.</td></tr>
<tr><td>Safety precautions</td><td colspan="8">Under very dusty conditions respiratory protection and protective clothes/gloves may be recommended to reduce the hazard from resuspended activity.</td></tr>
<tr><td colspan="9">Waste</td></tr>
<tr><td>Amount and type</td><td colspan="8">*Amount*: $5.5\ 10^{1} – 7\ 10^{1}$ kg m^{-2} if 5 cm depth removed.
Type: Soil and turf.</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td rowspan="5">Averted doses</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239 (% reduction in resuspension dose)</td></tr>
<tr><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td>35-40</td><td>40-45</td><td>45-50</td><td>60-65</td><td>5-10</td><td>15-20</td><td>15-20</td><td>30-35</td></tr>
<tr><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Effective implementation of option over a large area.
Reductions in external and resuspension doses received by a member of public living in the area will depend on the amount of the area covered by grass and the time spent by individuals on or close to grassed areas.
Time of implementation. The impact of removing the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td>Operator time</td><td colspan="8">$1\ 10^{1}$ m^{2} h^{-1} team^{-1}.
Team size: 1 to remove topsoil and turf. Up to 4 people if additional work is carried out to replace soil, reseed or returf.</td></tr>
<tr><td>Factors influencing costs</td><td colspan="8">Soil type, condition and depth removed.
Amount of vegetation to be removed.
Weather.
Topography.
Size of area.
Evenness of ground surface.
Type of equipment used.
Access.</td></tr>
<tr><td colspan="9">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="8">Soil erosion risk.
Possible adverse impact on bio-diversity.
Loss of plants, shrubs etc.
Possible loss of soil fertility.
Disposal or storage of waste. However, this issue may be minimised through the control of any disposal route and relevant authorisations.</td></tr>
<tr><td>Social impact</td><td colspan="8">Adverse aesthetic effect of removal, even if replaced.
Access to public areas may need to be restricted temporarily before turf and topsoil removal is implemented and afterwards while grass grows / turf settles.
Waste disposal may not be acceptable.
Loss of public amenities.</td></tr>
<tr><td>Practical experience</td><td colspan="8">Tested on semi-large scale (~ 400 m^{2}) on several occasions in the Former Soviet Union. Carried out on a large scale by the Russian authorities after the Chernobyl accident, but not optimised with respect to contaminant distribution, and not carried out consistently over a large area.</td></tr>
<tr><td>Key references</td><td colspan="8">Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R,</td></tr>
</table>

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45 Top soil and turf removal (manual)

	Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Fogh CL, Andersson KG, Barkovsky AN, Mishine AS, Ponamarjov AV, Ramzaev VP and Roed J (1999). Decontamination in a Russian settlement. *Health Physics*, **76**, (4), 421-430. Roed J, Lange C, Andersson KG, Prip H, Olsen S, Ramzaev VP, Ponomarjov AV, Varkovsky AN, Mishine AS, Vorobiev BF, Chesnokov AV, Potapov VN and Shcherbak SB (1996). *Decontamination in a Russian settlement.* Risø National Laboratory, Risø-R-870, ISBN 87-550-2152-2.
Version	2
Document history	See Table 3.2. Called 'Top soil removal by machines' in STRATEGY 2003. Datasheet called 'Soil/turf removal' in UK Handbook 2005 split into 2 datasheets in EURANOS 2005 called 'Top soil and turf removal (mechanical)' and 'Top soil and turf removal (manual)'.

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46 Top soil and turf removal (mechanical)

Objective	To reduce inhalation and external beta and gamma doses from contamination on outdoor grassed and soil areas within inhabited areas.
Other benefits	Removal of contamination from grassed and soil areas. Removal of activity from grass areas in gardens may reduce subsequent contamination of soil used for growing food. This in turn may reduce uptake to food crops grown.
Management option description	Turf and the top 50 mm of topsoil are removed. The removal may be carried out by bobcat mini-bulldozers, which are easy to manoeuvre in small areas, or by other similar equipment. The scale of equipment used will depend on the size of the area. Any plants and shrubs may need to be removed first. Optionally, the soil can be replaced and can be reseeded or re-turfed depending on the size of the area. This option is likely to give rise to dust, so application of water to dampen the surface or the use of a tie-down material is recommended prior to implementation to limit the resuspension hazard if removal is implemented in the first few months following deposition (Datasheet 44). In the longer term, most of the contamination is attached to soil particles and is not in the respirable range.
Target	Grass surfaces in gardens, parks, playing fields and other open spaces. Not recommended on land that has been tilled since the incident occurred.
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides alone.
Scale of application	Any size.
Time of application	Maximum effectiveness will be achieved for several years after deposition has occurred since most contaminants migrate only very slowly down the soil profile. May be beneficial to wait until after the first rain so that most of the dust has washed off other outdoor surfaces and buildings onto soil and grass areas.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Waste disposal of collected waste. Listed and other historically important sites and conservation areas.
Environmental constraints	Severe cold weather. Soil texture. In extreme cases, the slope of the area maybe a constraint.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of between 10 and 30 can be achieved if the removal depth is optimised. If a standard removal depth is used, the effectiveness will reduce in time after this as contamination migrates to deeper soil depths.
Reduction in surface dose rates	External gamma and beta dose rates above the soil surface will be reduced by approximately the value of the DF.
Reduction in resuspension	Resuspended activity in air above the surface will be reduced by the value of the DF.
Technical factors influencing effectiveness	Weather conditions. Soil texture: dry, crumbly soils will be more difficult to remove completely. Evenness of ground. Consistency in effective implementation. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Time of operation (contamination migrates into the soil over time).
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	(Depends on the size of the area being treated.) Motorised scraper. Grader or bulldozer. Seeding machine (if required). Transport vehicles for equipment and waste.
Utilities and infrastructure	Roads for transport of equipment, materials and waste.
Consumables	Fuel and parts for transport vehicles and equipment. Top soil. Plants and turf or grass seed.
Skills	Only a little instruction is likely to be required. Skilled personnel will be required if large-scale equipment is used. Care must be taken to remove soil to the optimal depth, and not plough the contamination into the cleaned surface.

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46 Top soil and turf removal (mechanical)

Safety precautions	Under very dusty conditions respiratory protection and protective clothes/gloves may be recommended to reduce the hazard from resuspended activity.
Waste	
Amount and type	*Amount:* $5.5\ 10^{1} – 7\ 10^{1}$ kg m^{-2} if 50 mm depth removed. *Type:* Soil and turf.
Doses	
Averted doses	**Dry deposition:** reductions of approx 30 % in external gamma dose rate received by a member of the public living in an inhabited area could be expected shortly after decontamination of the soil or grass surfaces. **Wet deposition:** reductions of approx 65 %.
Factors influencing averted dose	Effective implementation of option over a large area. Reductions in external and resuspension doses received by a member of public living in the area will depend on the amount of the area covered by grass and the time spent by individuals on or close to grassed areas. Time of implementation. The impact of removing the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) Exposure routes from transport and disposal of waste are not included.
Intervention costs	
Operator time	$1\ 10^{2} – 4\ 10^{2}$ m^{2}/team.hr for soil removal. If the area is returfed, this is the slowest task with work rates of 80 – 100 m^{2} / team hr. (Depends on equipment used. Likely to be much slower in small areas.) Team size: 2 people for soil and turf removal. In large areas, soil replacement could require an additional 2 people, returfing an additional 6 people and reseeding an additional 4 people.
Factors influencing costs	Soil type, condition and depth removed. Amount of vegetation to be removed. Weather. Topography. Size of area. Evenness of ground surface. Type of equipment used. Access.
Side effects	
Environmental impact	Soil erosion risk. Possible adverse impact on bio-diversity. Loss of plants, shrubs etc. Possible partial loss of soil fertility and may, in some cases, remove the entire fertile layer. Disposal or storage of waste. However, this issue may be minimised through the control of any disposal route and relevant authorisations.
Social impact	Adverse aesthetic effect of removal, even if replaced. Access to public areas may need to be restricted temporarily before turf and topsoil removal is implemented and afterwards while grass grows / turf settles. Waste disposal may not be acceptable. Loss of public amenities in the short term.
Practical experience	Tested on semi-large scale (~ 2000 m^{2}) on several occasions in the Former Soviet Union.
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, **46**, (2), 207-223. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for

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46 Top soil and turf removal (mechanical)

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Version	2
Document history	See Table 3.2. Called 'Top soil removal by machines' in STRATEGY 2003. Datasheet called 'Soil/turf removal' in UK Handbook 2005 split into 2 datasheets in EURANOS 2005 called 'Top soil and turf removal (mechanical)' and 'Top soil and turf removal (manual)'.

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47 Triple digging

Objective	To reduce inhalation and external gamma and beta doses from contamination arising from outdoor areas covered in grass or soil within inhabited areas (with minimal fertility loss).
Other benefits	None
Management option description	Using a spade, the order of three vertical layers of soil is changed. The thin top layer of soil and vegetation (about. 5 cm thick - optimised according to contamination depth) is inverted and buried at the bottom. The bottom layer (about 15 - 20 cm thick) is placed on top of this; and the intermediate layer (about. 5 – 15 cm thick), which should not be inverted in order to maintain fertility, is placed on the top. Contamination that was on the surface, or within the topmost few centimetres, is thereby well shielded. Large plants and shrubs may need to be removed before digging and the area may need to be subsequently replanted and reseeded with grass or re-turfed. The mixing of contamination by triple digging is irreversible and will severely complicate subsequent removal of contamination. In dry conditions, this option may give rise to dust, so application of water to dampen the surface is recommended prior to implementation to limit the resuspension hazard. Other digging methods may be more suitable and are described in Datasheet 39 (manual digging) and Datasheet 42 (rotovating). Triple digging must not be repeated, as this could bring contamination back to the surface.
Target	Grass and soil surfaces in gardens or other small open spaces, which have not been tilled since deposition.
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides.
Scale of application	Suitable for small soil/grass areas only (e.g. gardens).
Time of application	Maximum effectiveness will be achieved for several years after deposition has occurred because the contamination would remain in the top 5 cm for many years. Triple digging will remain effective for up to 10 years after deposition although the effectiveness will decrease with time unless the depth of the top layer of soil buried is increased so that all contamination is buried. It may be beneficial to wait until after the first rain so that most of the dust has washed off other outdoor surfaces and buildings onto grass/soil.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Cultural heritage protection.
Environmental constraints	Severe cold weather. Soil texture. In extreme cases, the slope of the area may be a concern.
Effectiveness	
Reduction in contamination on the surface	The decontamination factor (DF) will be 1 because no contamination is removed by this option.
Reduction in surface dose rates	External gamma dose rates above the surface can be expected to be reduced by a factor of between 5 and 10 for medium to high energy gamma emitters, such as caesium. The reduction in dose rate will depend on the radionuclides involved, i.e. their gamma energies. To achieve the reductions given above all the contamination in the top layer needs to be buried. Beta dose rate reduction is likely to be 100 % if the technique is implemented effectively.
Reduction in resuspension	Resuspended activity in air above the grass/soil surface will be reduced to zero if the technique is implemented effectively.
Technical factors influencing effectiveness	Correct implementation: it is important that all the surface contamination is buried to achieve the quoted reduction factor. Soil type and condition: if soil is very dry and loose, it is unlikely that triple digging can be implemented effectively. Size of area: digging over large areas will lead to higher surface dose rate reductions. Whether soil has been tilled since deposition. Time of implementation. If contamination has migrated below the top layer (~ 5 cm), technique will be less effective. High groundwater level may impede deep digging.
Social factors influencing effectiveness	None
Feasibility	
Equipment	Spades.
Utilities and infrastructure	None
Consumables	None

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47 Triple digging

Skills	Only a little instruction is likely to be required. People need to be fit due to the physical nature of the work.
Safety precautions	Personal protective equipment (PPE).
Waste	
Amount and type	None
Doses	
Averted doses	Not estimated but are likely to be similar to manual digging (Datasheet 39) and skim and burial ploughing (Datasheet 43).
Factors influencing averted dose	Effective implementation of option over a large area. Reductions in external and resuspension doses received by a member of public living in the area will depend on the amount of the area covered by grass and the time spent by individuals on or close to grassed areas. Time of implementation. The impact of triple digging on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering. If only soil areas are dug, need to consider other options for grass areas.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)
Intervention costs	
Operator time	2 – 3 m^2/team.hr (team size: 1 person).
Factors influencing costs	Soil type and condition (e.g. moisture, season). Weather. Topography. Evenness of ground surface. Access to gardens and other areas. Use of personal protective equipment (PPE).
Side effects	
Environmental impact	Soil erosion risk. The procedure brings contamination closer to the groundwater. May reduce fertility. Severely complicates subsequent removal of contamination, as more waste will be generated and mixing will make segregation of contaminated waste more difficult. Acceptability of smothering flora and fauna and destruction of garden planting and amenity areas.
Social impact	Adverse aesthetic effect (especially for grassed areas). Acceptability of leaving contamination in-situ. Restriction of some future gardening activities (e.g. banning digging to depths of 200 mm or greater).
Practical experience	Tested several times after the Chernobyl accident, in ca. 100-200 m^2 plots in the Former Soviet Union.
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, **46**, (2), 207-223. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). *Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. Roed J, Andersson KG and Prip H. (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p. Roed J, Andersson KG, Fogh CL, Barkovski AN, Vorobiev BF, Potapov VN, Chesnokov AV (1999). Triple Digging – a simple method for restoration of radioactively contaminated urban soil areas. *Journal of Environmental Radioactivity*, **45**, (2), 173-183.
Version	2
Document history	See Table 3.2.

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48 Turf harvesting

Objective	To reduce external beta and gamma doses from contamination in outdoor grassed areas within inhabited areas, and reduce inhalation doses from material resuspended from these areas.
Other benefits	Removal of contamination from grassed areas. Removal of activity from grass areas in gardens may reduce subsequent contamination of soil used for growing food. This in turn may reduce up-take to food crops grown.
Management option description	Turf is removed, optionally followed by reseeding or returfing. Removal is carried out using a turf harvester which skims off a thin layer of soil/root mat (about 1 cm) with the turf in rolls or slabs. These machines are available in various sizes. Manual turf removal is considered in Datasheet 45. This option is likely to give rise to dust, so application of water to dampen the surface or the use of a tie-down material is recommended prior to implementation to limit the resuspension hazard (Datasheet 44).
Target	Grass surfaces in gardens, parks, playing fields and other open spaces. Grassed areas must be mature, i.e. they must have an established root mat.
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides alone.
Scale of application	Any size.
Time of application	Maximum benefit if carried out soon after deposition before weathering of activity from the grass to the underlying soil occurs. However will continue to be effective for several years after deposition has occurred as some activity will remain in the root mat of the turf. May be beneficial to wait until after first rain so that most of dust has washed off other outdoor surfaces and buildings onto grass areas.
Constraints	
Legal constraints	Liabilities for possible damage to property. Listed and other historically important sites and conservation areas. Ownership and access to property. Waste disposal of collected waste.
Environmental constraints	Severe cold weather. In extreme cases, the slope of the area maybe a constraint. Evenness of the ground. Turf harvesting equipment is very sensitive to stones and rocks.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of 3 - 10 can be achieved if this option is implemented soon deposition. The effectiveness will reduce in time after this as contamination migrates to deeper soil depths.
Reduction in surface dose rates	External gamma and beta dose rates in air above a grass surface will be reduced by approximately the value of the DF.
Reduction in resuspension	Resuspended activity in air above the grass surface will be reduced by the value of the DF.
Technical factors influencing effectiveness	Weather, particularly those at the time of deposition, and the amount of rain after deposition. Correct implementation of option – all turf must be collected to achieve the DF values quoted. Once contamination has migrated below the turf layer, the technique will start to become less effective. Soil texture (does the soil contain stones? etc.). Evenness of ground. Effective implementation. Size of the area covered by grass. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Whether recovery options have been applied to adjacent ground surfaces.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	(Depends on the size of the area being treated.) Sod cutter/turf harvester (commercial and domestic sizes). Seeding machine (if required). Transport vehicles for equipment and waste.
Utilities and infrastructure	Roads (transport of equipment, materials and waste).
Consumables	Fuel and parts for transport vehicles and equipment. Turf or grass seed.
Skills	Only a little instruction is likely to be required. Skilled personnel may be required if large scale equipment is used.

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47 Triple digging

<table>
<tr><td>Safety precautions</td><td colspan="8">Under very dusty conditions respiratory protection and protective clothes/gloves may be recommended.</td></tr>
<tr><td colspan="9">Waste</td></tr>
<tr><td>Amount and type</td><td colspan="8">*Amount:* $2\ 10^1 – 3\ 10^1$ kg m^{-2} if 2 – 2.5 cm depth removed.
Type: Soil and turf.
Segregation of contaminated waste is likely to be difficult. Monitoring of waste to determine if it meets current waste disposal criteria will be important to ensure that the quantity of waste requiring special management is minimised.</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td rowspan="5">Averted doses</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239 (% reduction in resuspension dose)</td></tr>
<tr><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td>35-40</td><td>40-45</td><td>45-50</td><td>60-65</td><td>5-10</td><td>15-20</td><td>15-20</td><td>30-35</td></tr>
<tr><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Effective implementation of option over a large area.
Reductions in external and resuspension doses received by a member of public living in the area will depend on the amount of the area covered by grass and the time spent by individuals on or close to grassed areas.
Time of implementation. The impact of removing the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Whether adjacent soil surfaces are also decontaminated.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)
• inhalation of dust generated
• *inadvertent ingestion of dust from workers' hands*
Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE.
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td>Operator time</td><td colspan="8">$1.5\ 10^2 – 1\ 10^3\ m^2$/team.hr for turf removal (depends on equipment used. Tractors with attached modern turf harvesters can strip about 1200 m^2/hr).
Team size: 2 people for turf removal. For turf-laying, an additional 4 people would be required in the team.</td></tr>
<tr><td>Factors influencing costs</td><td colspan="8">Soil type and condition.
Weather.
Topography.
Size of area.
Evenness of ground surface.
Type of equipment used.
Access.</td></tr>
<tr><td colspan="9">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="8">Possible adverse impact on bio-diversity.
Disposal or storage of waste. However, this issue may be minimised through the control of any disposal route and relevant authorisations.
Risk of soil erosion.</td></tr>
<tr><td>Social impact</td><td colspan="8">Adverse aesthetic effect of turf removal, even if replaced.
Access to public areas may need to be restricted temporarily before turf removal is implemented and afterwards while grass grows / turf settles.
Loss of public amenities in short-term.
Waste disposal may not be acceptable.</td></tr>
<tr><td>Practical experience</td><td colspan="8">Tested on relatively large meadows in the Former Soviet Union.</td></tr>
<tr><td>Key references</td><td colspan="8">Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark.
Andersson KG, Rantavaara A, Roed J, Rosén K, Salbu B and Skipperud L (2000). *A guide*</td></tr>
</table>

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Version	2
Document history	See Table 3.2.

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49 Peelable coatings

Objective	To reduce inhalation and external gamma and beta doses from contamination on external walls and roofs of buildings and paved/road surfaces within inhabited areas.
Other benefits	Will remove contamination from external building surfaces and paved/road surfaces. Peelable coatings will also stop inhalation doses from resuspended material to the public and workers implementing recovery options while they are in place (tie-down).
Management option description	Detex or Pelableau are examples of peelable coating. Other materials may be appropriate for use as peelable coatings (e.g. PVA). Detex: On buildings, Detex is applied by brush because it is difficult to use in a spray gun. Brushing will also force the liquid into surface areas and crevices, which is better for decontamination. On flat surfaces, it can be poured manually and spread using metal rakes. After curing (45 minutes – 2 hours), the rubber film is removed with a knife or by peeling. The contamination adheres to the peeled film, which is then disposed of as solid active waste. Pelableau: Pelableau is sprayed onto the surface using an airless pump. After curing it is peeled off. It is not widely available and not suitable for use on roofs, thereby reducing its usefulness.
Target	External walls and roofs of buildings. Paved surfaces (roads, pavements, paths, etc).
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides alone. As a tie-down option: alpha emitting radionuclides that give rise to inhalation doses from resuspended material.
Scale of application	Suitable for small areas (e.g. houses, pavements, playgrounds). Unlikely to be suitable for large areas as the coatings can be very difficult to remove intact when used on large surface areas.
Time of application	Maximum benefit if carried out soon after deposition when maximum contamination is still on the surface. The peelable coating will be effective in stopping resuspension over the period that it remains intact.
Constraints	
Legal constraints	Liabilities for possible damage to property. Use on listed buildings, historically important sites & conservation areas. Solid waste disposal legislation. Ownership and access to property.
Environmental constraints	Severe cold weather. Cannot be applied in wet weather.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of up to 5 can be achieved if this removal option is implemented within a few weeks of deposition. This option is likely to be most effective when used on smooth surfaces (see Datasheet 49 for more information on the use of peelable coatings on metal surfaces). Later application is likely to give a lower DF, particularly on porous building materials such as bricks and tiles. Repeated application may provide additional benefit, i.e. an increase in the contamination removed.
Reduction in surface dose rates	External gamma and beta dose rates dose rates from external walls and roofs will be reduced by approximately the value of the DF.
Reduction in resuspension	In the long term, resuspended activity in air adjacent to surfaces will be reduced by a resuspension reduction factor (RRF) of 5. While the peelable coating is in place, resuspended activity in air will be reduced by almost 100%.
Technical factors influencing effectiveness	Weather conditions & temperature. Type, evenness and condition of surface. Time of operation: the longer the time between deposition and implementation of the option the less effective it will be due to fixing of the contamination to the surface. Consistent application of peelable coating over the contaminated area. Viscosity of applied liquids. Amount of buildings and paved surfaces in the area. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Ladders. Scaffolding. Brushes. Metal rake. Airless spray pump and compressor. Transport vehicles for equipment and waste.
Utilities and infrastructure	Roads for transport of equipment, materials and waste.

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49 Peelable coatings

<table>
<tr><td>Consumables</td><td colspan="8">Peelable coating.
Fuel and parts for equipment and transport vehicles.</td></tr>
<tr><td>Skills</td><td colspan="8">Skilled personnel essential to apply (and remove) coating.</td></tr>
<tr><td>Safety precautions</td><td colspan="8">Protective clothing.
For tall buildings lifelines and safety helmets will be required.</td></tr>
<tr><td colspan="9">Waste</td></tr>
<tr><td>Amount and type</td><td colspan="8">Amount: 1 kg m^{-2}. Type: Rubber-like material.</td></tr>
<tr><td colspan="9">Doses</td></tr>
<tr><td rowspan="5">Averted doses</td><td colspan="4">Cs-137 (% reduction in external dose)</td><td colspan="4">Pu-239 (% reduction in long term resuspension dose after removal)</td></tr>
<tr><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td><td colspan="2">Over 1st year</td><td colspan="2">Over 50 years</td></tr>
<tr><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td><td>Dry</td><td>Wet</td></tr>
<tr><td>5-10</td><td><5</td><td>5-10</td><td><5</td><td>0</td><td><5</td><td><5</td><td>0</td></tr>
<tr><td colspan="8">The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.</td></tr>
<tr><td>Factors influencing averted dose</td><td colspan="8">Consistency in effective implementation of option over a large area.
Population behaviour in area.
Amount of buildings in the area i.e. environment type/land use.
Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.</td></tr>
<tr><td>Additional doses</td><td colspan="8">Relevant exposure pathways for workers are:
• external exposure from radionuclides in the environment and contaminated equipment
• inhalation of radioactive material resuspended from the ground and other surfaces
• inhalation of dust generated
• *inadvertent ingestion of dust from workers' hands*
Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE.
Exposure routes from transport and disposal of waste are not included.</td></tr>
<tr><td colspan="9">Intervention costs</td></tr>
<tr><td>Operator time</td><td colspan="8">7 – 5 10^{1} m^{2}/team.hr.
Team size: 2 people.</td></tr>
<tr><td>Factors influencing costs</td><td colspan="8">Weather.
Building size / height / pitch of roof.
Type of equipment used.
Access.
Evenness of surface.
Size of area to be treated.</td></tr>
<tr><td colspan="9">Side effects</td></tr>
<tr><td>Environmental impact</td><td colspan="8">The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.</td></tr>
<tr><td>Social impact</td><td colspan="8">Method of disposing such a large quantity of contaminated waste may not be acceptable to local residents.
Treatment will have the positive benefit of cleaning surfaces.</td></tr>
<tr><td>Practical experience</td><td colspan="8">None</td></tr>
<tr><td>Key references</td><td colspan="8">Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315
Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR</td></tr>
<tr><td>Version</td><td colspan="8">2</td></tr>
<tr><td>Document history</td><td colspan="8">See Table 3.2.</td></tr>
</table>

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50 Snow removal

Objective	To reduce inhalation and external gamma and beta doses from contamination on external walls and roofs of buildings and paved/road surfaces within inhabited areas.
Other benefits	Will remove contamination from outdoor surfaces.
Management option description	If deposition occurs in open areas covered by a thick layer of snow, the removal of the snow layer before the first thaw will prevent the contaminants from reaching the underlying ground surface. Generally, soil areas will be most important to treat, but the method could also be applied on paved surfaces. If the snow cloud was contaminated, all the snow should be removed. The removal can be carried out by 'Bobcat' mini-bulldozers (easy to manoeuvre in small areas) or similar available equipment. Alternatively removal can be undertaken with spades, shovels, pokers or manual scrapers. However, these alternatives are much slower. Snow removal from roofs should also be considered. Walls would very seldom be sufficiently contaminated by snow to require special action. Trees/shrubs can be removed / pruned as described in Datasheet 52.
Target	Snow covered open areas, particularly grassed areas and other areas of soil, e.g. parks, playing fields and gardens.
Targeted radionuclides	All radionuclides. Short-lived radionuclides if implemented quickly.
Scale of application	Any size. Suitable for small areas (e.g. gardens) and large areas (e.g. parks, playing fields etc).
Time of application	Maximum benefit if carried out as soon as possible after deposition. Must be carried out before the first thaw following the contamination.
Constraints	
Legal constraints	Ownership and access to property. Liabilities for possible damage to property. Waste disposal legislation.
Environmental constraints	Snow storms can make it very difficult to carry out the work. In extreme cases, the slope of the area may be a constraint (depends on operator skill). Obstacles e.g. trees / shrubs.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of between 10 and 30 can be achieved if this option is carried out prior to the snow melting and as long as snow is removed to a depth to include the contamination.
Reduction in surface dose rates	External dose rates above the snow covered surfaces will be reduced by a value similar to the DF. If snow fall occurs post deposition, external beta dose rates above the snow surface are likely to be negligible prior to removal.
Reduction in resuspension	Resuspended air concentrations above the surface will be reduced by a value similar to the DF. Resuspension from a snow-covered surface will be generally low. If snow falls after deposition, the resuspended air concentrations above the snow surface will be zero prior to removal.
Technical factors influencing effectiveness	Effective and consistent application of option over a large area. Time of implementation. The impact of snow removal will be reduced with time as snow melt starts. Over time, snow may form drifts leading to areas of enhanced contamination. The snow layer must be sufficiently thick to allow complete removal of the snow surface. If, for example, human activity has compressed the snow, complete removal will be more difficult.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Bobcat mini-bulldozer or similar equipment (e.g. tractor with scraper), or spades, shovels, pokers or manual scrapers. Vehicles for transporting equipment and waste.
Utilities and infrastructure	Roads for transporting equipment and waste.
Consumables	Fuel and parts for vehicles.
Skills	Little instruction is required. On a local scale, snow removal from the ground could by the inhabitants of the affected area as a self-help measure, after instruction from authorities and provision of safety and other required equipment. However, the manual work requires hard physical work, which not all people would be able to do.
Safety precautions	Waterproof clothing, boots and gloves.

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50 Snow removal

	In case of dry frost / storm weather, respiratory protection should be considered if carrying out the procedure soon after contamination.	
Waste		
Amount and type	Depends on thickness of the snow layer. 5 cm snow = 0.5 kg m^{-2} waste.	
Doses		
Averted doses	**Dry conditions:** reductions of approx 35 % in external gamma dose rate received by a member of the public living in an inhabited area could be expected shortly after decontamination of the snow covered surface. **Wet deposition:** reductions in dose rates are likely to be much higher, at around 80%.	
Factors influencing averted dose	Population behaviour in area: the time spent by individuals on or close to snow covered surfaces. Amount of the area containing snow covered surfaces.	
Additional doses	Relevant exposure pathways for workers are: external exposure from radionuclides in the environment and contaminated equipment inhalation of radioactive material resuspended from the ground and other surfaces Exposure routes from transport and disposal of waste are not included.	
Intervention costs		
Operator time	Work rate (m^2/team.hr)	2.5 10^2 - 5 10^2 (manual removal would probably be about a factor of 5 slower). Includes loading to waste transport truck.
	Team size (people)	1
Factors influencing costs	Weather. Topography. Size of area. Thickness of snow layer to be removed. Type of equipment used. Access. Use of personal protective equipment (PPE).	
Side effects		
Environmental impact	The disposal of the waste water from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.	
Social impact	Public reassurance. Limited adverse aesthetical effect, due to the use of relatively heavy machinery in garden areas.	
Practical experience	Successfully tested on relatively small scale in Norway.	
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson, K. G. and Roed, J. (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, **46**, (2), 207-223. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Qvenild C and Tveten U (1984). *Decontamination and winter conditions*. Institute for Energy Technology, Kjeller, Norway, ISBN 82-7017-067-4, 1984.	
Version	2	
Document history	See Table 3.2.	

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51 Collection of leaves

Objective	To reduce inhalation and external gamma and beta doses from fallen leaves within inhabited areas. Mainly for use when deposition has occurred under dry conditions and when trees and shrubs are in leaf. After wet deposition, consideration should be given to decontaminating the ground under trees as most of the contamination washes straight off the trees.
Other benefits	None
Management option description	Collection of leaves (deciduous trees & shrubs), needles and pinecones (coniferous trees). Leaves that have fallen from trees are collected and disposed of or composted. Additional decontamination may also be necessary for surfaces under trees/shrubs. It is not appropriate to use any sort of chemical spray to speed up the process of leaf fall as this would cause an additional environmental hazard. As conifers will shed needles over a number of years (2 – 7), repeated application may be beneficial after the first leaf fall material has been collected.
Target	Trees and shrubs in inhabited areas that are in leaf at the time of deposition.
Targeted radionuclides	All radionuclides. Short-lived radionuclides if the time between deposition and leaf drop is short.
Scale of application	Any size.
Time of application	**Deciduous trees:** Collection must be carried out soon after leaf fall before weathering moves activity from leaves to underlying soil, leaves blow to contaminate adjacent areas or compost into soil. **Coniferous trees:** Maximum benefit if collection of pine cones is in the autumn when the needle fall for the year has finished.
Constraints	
Legal constraints	Ownership and access to property. Waste disposal of collected leaves.
Environmental constraints	Slope of land (if extreme).
Effectiveness	
Reduction in contamination on the surface	Most contamination on trees and shrubs is associated with the leaves. So, the decontamination factor (DF) is likely to be similar to that for tree removal if leaves are on the trees at the time of deposition and all the leaves are collected (Datasheet 52). This option will be less effective for coniferous trees, even if collection is repeated several times.
Reduction in surface dose rates	External gamma and beta dose rates surrounding shrubs and trees will be significantly reduced if leaves are collected.
Reduction in resuspension	Resuspended activity in air adjacent to the shrubs and trees will be significantly reduced if leaves are collected.
Technical factors influencing effectiveness	Weather conditions e.g. windy conditions will hamper attempts to collect all contaminated leaves. Collection of all contaminated leaves; once they disperse or begin to compost, the technique will become less effective. Some contamination may transfer from leaves to the underlying surfaces. Consistency in effective implementation of option over a large area. Number of trees/shrubs in the area and tree species. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Leaf blowers. Garden vacuum equipment. Rakes. Wheelbarrows. Municipal vehicles for slurry collection would also be very efficient in sucking up leaves and could be applied on a large scale in the autumn. Transport vehicles for equipment and waste.
Utilities and infrastructure	Roads (transport of equipment, materials and waste).
Consumables	Fuel and parts for equipment and vehicles.
Skills	Only a little instruction is likely to be required. The method could be implemented by inhabitants of the affected area as a self-help measure, after instruction from authorities. Provision of safety and other required equipment may be required.

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51 Collection of leaves

Safety precautions	Gloves and overalls. Respiratory protection, especially in dusty conditions.
Waste	
Amount and type	*Amount*: 5 10^{-1} kg m^{-2}. *Type:* leaves / pine needles / pinecones.
Doses	
Averted doses	Most contamination is associated with leaves. Figure 1.4 gives an indication of the likely importance of trees in contributing to long-term external doses. Reductions in external gamma dose rate received by a member of the public living in an inhabited area shortly after leaf collection could be expected to be similar to those given for tree removal (Datasheet 52) if the trees were predominantly deciduous.
Factors influencing averted dose	Consistency in effective implementation of option over a large area. Population behaviour in area. Number of trees/shrubs in the area i.e. environment type/land use. Time of implementation. The impact of removing leaves on the overall doses will be reduced with time as there will be less contamination on the leaves due to natural weathering.
Additional doses	Exposure pathways workers could be exposed to are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) • inhalation of dust generated • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics are will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included.
Intervention costs	
Operator time	2 10^2 m^2/team.hr (team size: 1 person).
Factors influencing costs	Weather. Access. Size of area. Underlying surface. Type of equipment used. Access.
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	Collection of fallen leaves will make the area look tidier. Temporary restriction of access to public areas. Waste disposal may not be acceptable. Trees remain in place (positive benefit for wildlife and the area).
Practical experience	None
Key references	Morgan CJ (1987). Methods and cost of decontamination and site restoration following dispersion of plutonium in a weapon accident. Aldermaston, AWE, SCT Laboratory.
Version	2
Document history	See Table 3.2.

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52 Tree & shrub pruning / removal

Objective	To reduce inhalation and external gamma and beta doses from contamination on trees and shrubs within inhabited areas. Mainly for use when deposition has occurred under dry conditions and when trees and shrubs are in leaf. After wet deposition, consideration should be given to decontaminating the ground under trees as most of the contamination washes straight off the trees.
Other benefits	Removal of contamination from areas containing trees. Removal of activity from gardens may reduce subsequent contamination of soil used for growing food. This in turn may reduce uptake to food crops grown.
Management option description	Removal or heavy pruning of trees and shrubs with the option of replacement. Most importantly, leaves must be removed. If tree felling is conducted on a small scale, incineration of the waste is an option. Smaller prunings and leaves can be shredded for composting. This option may give rise to large amounts of dust. However, the use of water to dampen the tree surface or the use of a tie-down material is unlikely to be practicable and so workers should be given personal protective equipment (PPE) to protect them against the resuspension hazard, if this hazard is significant. It may be possible to ask inhabitants of the affected area to prune trees and shrubs as a 'self-help' option.
Target	Highly contaminated trees and shrubs in inhabited areas that are in leaf at the time of deposition. Coniferous trees may contribute more to external doses in the long term as they don't lose their leaves annually. However, the overall contributions of deciduous and coniferous trees to external doses depend on the fate of fallen leaves.
Targeted radionuclides	All long-lived radionuclides, not short-lived radionuclides alone.
Scale of application	Any size. Incineration of waste is only an option on a small scale.
Time of application	For maximum benefit, tree felling should take place within the first month after deposition, and before weathering of activity to the underlying soil has occurred. In addition, it is important that it is completed before leaf fall for deciduous trees.
Constraints	
Legal constraints	Liabilities for possible damage to gardens or property. Ownership and access to property. Use at listed or other historical sites and in conservation areas.
Environmental constraints	Severe cold weather. Soil type and texture. Extent of root, if it is necessary to remove the root ball.
Effectiveness	
Reduction in contamination on the surface	The reduction in contamination is proportional to the fraction of the tree/shrub removed. If a whole tree is felled and all the leaves are collected, a very high decontamination factor (DF) could be achieved. In practice, a DF of up to about a factor of 50 could be achieved.
Reduction in surface dose rates	External gamma and beta dose rates from shrubs and trees will be reduced by approximately the value of the DF.
Reduction in resuspension	Resuspended activity in air adjacent to the shrubs and trees will be reduced by a value similar to the DF.
Technical factors influencing effectiveness	Degree of pruning or removal and effectiveness of leaf collection. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Tree type: coniferous trees have a continuous turnover of leaves and it may take several years to lose all the needles initially contaminated.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Tractor and trailer. Chainsaw. Axes / cutters. Ropes and ladders (tall trees). Shredder. An incinerator may be used for waste from small areas. Transport vehicles for equipment and waste.
Utilities and infrastructure	Roads (transport of equipment, materials and waste). Power supply.

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52 Tree & shrub pruning / removal

Consumables	Fuel and parts for equipment and vehicles. Tree saplings, if replacement option is implemented.	
Skills	Skilled personnel with experience in felling trees required for felling large trees.	
Safety precautions	Dry and dusty conditions: respiratory protection & protective clothing. Safety helmets. For tall trees, a lifeline should be used.	
Waste		
Amount	Tree felling: 1 10^{1} kg m^{-2}.	
Type	Wood and vegetation. May also get contaminated fruit from orchards.	
Doses		
Averted doses	**Dry deposition:** reductions of approx 20 % in external gamma dose rate received by a member of the public living in an inhabited area could be expected shortly after removal of contaminated trees/shrubs. **Wet deposition:** reductions in dose rate will be negligible.	
Factors influencing averted dose	Number of trees/shrubs in the area i.e. environment type/land use. Indoor doses are affected by the number of windows in buildings that are adjacent to trees, as much of the dose from trees is due to the lower protection offered by windows.	
Additional doses	Relevant exposure pathways for workers are: external exposure from radionuclides in the environment and contaminated equipment inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) Exposure routes from transport and disposal of waste are not included.	
Intervention costs		
Operator time	Felling only	Felling & tree replacement
	5 10^{1} m^{2}/team.hr Team size: 2 people	5 10^{1} m^{2}/team.hr (tree felling is the slowest task) Team size: 3 people (felling and replacement) Tree replacement has a work rate of about 4 10^{2} m^{2}/team.hr
Factors influencing costs	Type of trees / size and height of trees. Size of trees to be removed. Type of equipment used. Access. Distance to transport. Degree of removal.	
Side effects		
Environmental impact	Possible adverse impact on biodiversity. Possible soil erosion. Negative effect on birdlife. The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.	
Social impact	Adverse aesthetic effect. Acceptability of tree removal.	
Practical experience	Tested on a small scale in Europe after the Chernobyl accident.	
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, **46**, (2), 207-223. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR – Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Guillitte O and Willdrocht C (1993). An assessment of experimental and potential	

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52 Tree & shrub pruning / removal

	countermeasures to reduce radionuclide transfers in forest ecosystems. *Science of the Total Environment*, **137**, 273-288. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p. Schell WR, Linkov I, Myttenaere C and Morel B (1996). A dynamic model for evaluating radionuclide distribution in forests from nuclear accidents. *Health Physics*, **70**, (3), 318-335.
Version	2
Document history	See Table 3.2.

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53 Application of detachable polymer paste on metal surfaces

Objective	To reduce external doses arising from contamination on metal surfaces in industrial buildings. For information on the use of peelable coatings on other building surfaces, see Datasheet 49.
Other benefits	Removal of contamination from the area and prevent redistribution of contamination in buildings. May reduce resuspension doses in dusty environments.
Management option description	Application of polymer paste (based on PVA) for removal of contamination from metal surfaces. In particular it can be used for machinery and ventilation systems. The detachable coatings are liquids or gels. When the dry intact film has formed on the surface, the coating is peeled off by hand, removing any loose contamination. The technique can be applied easily and quickly and requires minimum equipment and personnel.
Target	Contaminated (industrial) metal surfaces in buildings and special parts of machinery, for example ventilation systems, hand tools, equipment.
Targeted radionuclides	All radionuclides. Not short-lived radionuclides alone.
Scale of application	Could be carried out on a small scale in highly contaminated industrial areas.
Time of application	Maximum benefit if carried out shortly after deposition.
Constraints	
Legal constraints	Liabilities for possible damage to property.
Environmental constraints	None
Effectiveness	
Reduction in contamination on the surface	75 – 97% reduction. The decontamination efficiency of different compounds has been tested on stainless steel, cast iron and brass. The efficiency factors presented here are based on small-scale laboratory and field experiments.
Reduction in surface dose rates	No estimates made. However, reductions in external dose rate above the surface should be similar to those above.
Reduction in resuspension	No estimates made.
Technical factors influencing effectiveness	Type of surface: if the metal is rusty or is peeling, decontamination is reduced by about 4 – 7 times Coatings require careful removal in order to be effective. Removal should be done by hand. Consistency in procedure application.
Social factors influencing effectiveness	None
Feasibility	
Equipment	None
Utilities and infrastructure	Transport vehicles for equipment. Scaffolding or mobile lifts for tall buildings, where channels may be mounted under the ceiling.
Consumables	Polyvinyl alcohol (PVA), which is water based. Paste made from PVA, EDTA, sodium carbonate and glycerine. Fuel.
Skills	Skilled personnel required. Industrial cleaning companies will have the required skills.
Safety precautions	Lifelines. Safety helmets. Respiratory protection.
Waste	
Amount & Type	0.2 – 1.8 kg m^{-2} solid waste.
Doses	
Averted doses	Not estimated.
Factors influencing averted dose	Amount of time spent in the vicinity of contaminated machinery and tools.
Additional doses	Relevant exposure pathways for workers are: external exposure from radionuclides in the environment and contaminated equipment enhanced resuspension leading to inhalation of dust Because of potentially high concentration levels, it is important to fully assess external dose rates in these areas prior to cleaning. Coatings are removed by hand so doses to workers may be significant.

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53 Application of detachable polymer paste on metal surfaces

Intervention costs	
Operator time	2 - 6 m^2 / team hr. Variable time for setting up scaffolding.
Factors influencing costs	Need for scaffolding /mobile lifts. Access to surfaces. Cost of specialist labour. Cost of chemicals.
Side effects	
Environmental impact	Disposal or storage of waste. This can be minimised through the control of any disposal route and relevant authorisations.
Social impact	Acceptability of disposal of contaminated waste. Reassurance of employees & users and maintaining continuity of work. Use of peelable coatings may have a positive effect on the appearance of surfaces.
Practical experience	Tested on a small-scale in Gomel province of Belarus after the Chernobyl accident. Two strippable coatings that were developed in the 1980's are waterborne vinyl resin and polybutyl dispersion, both of which are non-flammable, non-toxic and abrasion resistant (IAEA, 1989; Andersson and Roed, 1994).
Key references	Eged K, Kis Z, Andersson KG, Roed J and Varga K (2003). Guidelines for planning interventions against external exposure in industrial area after a nuclear accident. Part 1: a holostic approach to countermeasure application. GSF-Bericht 01/03, Germany. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). *Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3.
Version	2
Document history	See Table 3.2.

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54 Chemical cleaning of metal surfaces

Objective	To reduce external doses arising from contamination on metal surfaces in industrial buildings.
Other benefits	Removal of contamination from the area and prevent redistribution of contamination in buildings. May reduce resuspension doses in dusty environments.
Management option description	Industrial washing with chemical solutions. The decontamination processes usually involve the following steps: oxidation or reduction complexation: dissolution passivation: preparation of a corrosion-resistant, thermodynamically stable surface after removing of the contaminated surface layer There are 2 types of procedures: static (without flow) and dynamic (with flow). The dynamic method is useful for removing radionuclides from both internal and otherwise inaccessible surfaces. Depending on the chemicals applied, procedures are termed soft and hard techniques. Soft (mild) chemicals include non-corrosive reagents such as detergents, complexing agents, diluted acids or alkalis. These can be used when the object has to be treated without attacking the base material. Hard (aggressive) chemicals include concentrated strong acids or alkalis and other corrosive reagents. Chemical decontamination is usually carried out by circulating the selected reagents through a filter system. The chemical solution is contained in a tank in which a spraying system, placed near to or below the surface being cleaned, circulates the solution. Decontamination can also be carried out by immersion of the contaminated item (hand tools, special parts of machinery) in a bath.
Target	Contaminated (industrial) metal surfaces in buildings and special parts of machinery (tools).
Targeted radionuclides	All radionuclides. Not short-lived radionuclides alone.
Scale of application	Medium scale in highly contaminated industrial areas.
Time of application	Maximum benefit if carried out shortly after deposition.
Constraints	
Legal constraints	Liabilities for possible damage to property. Possible regulations on use of chemicals.
Environmental constraints	Chemical incompatibility. For example, if the system to be decontaminated previously contained special chemicals, this material can produce some explosive gases when put together with the decontamination chemical.
Effectiveness	
Reduction in contamination on the surface	**Soft techniques:** 50 – 90 % reduction. **Hard techniques:** > 90 % (up to 100 %) reduction.
Reduction in surface dose rates	No estimates made. However, reductions in external dose rates above the surface should be similar to those above.
Reduction in resuspension	No estimates made.
Technical factors influencing effectiveness	Treatment temperature (usually in the range of 20 – 90 °C). Chemical concentration. Flow rate of the applied chemical solution. Contact time. Surface type (less effective on porous surfaces). Chemical incompatibility. Consistency in procedure application. The bottom part of the building should be cleaned particularly well, as this will often be the closest to people working in the building.
Social factors influencing effectiveness	None
Feasibility	
Equipment	High pressure water washer. Spray machines. Other hand tools. Liquid tanks.
Utilities and infrastructure	Transport vehicles for equipment. Scaffolding or mobile lifts for tall buildings. Water and power supplies.

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54 Chemical cleaning of metal surfaces

	Pressurised air supply.
Consumables	Soft (mild) chemical decontamination First step: attack & dissolve metal oxide films, potassium permanganate ($KMnO_4$) (one of the best for Cs) or potassium hydroxide (KOH) or sodium hydroxide (NaOH) or trisodium phosphate (Na_3PO_4). Second step: bind and remove the radionuclides; detergent: any hydrophobic materials e.g. dodecyl benzene sulphuric acid; complexing: EDTA (one of the best for Cs) or oxalic acid ($C_2H_2O_4$) or citric acid ($C_6H_8O_6$) (one of the best for Cs). Third step: passivation by nitric acid (HNO3) or phosphoric acid (H_3PO_4) or sulphuric acid (H_2SO_4) or hydrogen peroxide (H_2O_2). Hard (strong) chemical decontamination First and third steps are the same as for the soft techniques, but at higher concentrations of the chemicals. Second step: detergent & complexing reagents; detergent: any hydrophobic materials e.g. dodecyl benzene sulphuric acid; complexing: sodium bisulphate ($NaHSO_4$) or sodium sulphate (Na_2SO_4) or ammonium oxalate ($(NH_4)_2C_2O_4{\bullet}H_2O$) or ammonium citrate $[(NH_4)_2HC_6H_5O_7]$ or EDTA.
Skills	Skilled personnel required. Knowledge and experience in corrosion technology, waste generation/removal techniques and chemical cleaning is needed. Industrial cleaning companies will have the required skills.
Safety precautions	Safety helmets and lifelines. Water proof safety clothing. Respiratory protection. Proper ventilation (because the tanks are usually open to the air).
Waste	
Amount & Type	5 – 30 l per m^2 liquid waste (applying a recycling system).
Doses	
Averted doses	Not estimated.
Factors influencing averted dose	Amount of time spent in or close to the buildings. Amount of the building that is covered in metal surfaces. Extent of decontamination of nearby surfaces.
Additional doses	Relevant exposure pathways for workers are: external exposure from radionuclides in the environment and contaminated equipment enhanced resuspension leading to inhalation of dust Exposure routes from transport and disposal of waste are not included.
Intervention costs	
Operator time	2 – 6 m^2/team hr. Variable time for setting up scaffolds/transport.
Factors influencing costs	Need for scaffolding /mobile lifts. Different types of treatment of surfaces and waste chemicals. Cost of specialist labour. Cost of chemicals.
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations. Electronic parts may be damaged by water if not dismounted. Damage to equipment due to the mechanical impact (e.g. the basic material will be thinner and rough). If strong chemicals are used they may lead to corrosive and toxic reagents being produced which will need to be handled and disposed of.
Social impact	Acceptability of disposal of contaminated waste and chemicals. Removal of the corrosion products from the surface; the metal surfaces are cleaned. Reassurance of employees & users and maintaining continuity of work.
Practical experience	Largely used during the decommissioning of Nuclear Power Plants (NPPs). Chemical decontamination is very effective at NPPs in normal practice.
Key references	Barkatt A, Spring S and Olzsovka SA (1995). *Removal of radioactive or heavy metal contaminanats by means of non-persistant complexing agents.* United States Patent and Trademark Office: United States Patent; No. 5435331.

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55 Chemical cleaning of plastic and coated surfaces

Objective	To reduce external doses arising from contamination on plastic and coated surfaces in industrial buildings.
Other benefits	Removal of contamination from the area and prevent redistribution of contamination in buildings. May reduce resuspension doses in dusty environments.
Management option description	Industrial washing with detergents or chemical solutions in multi-step processes. The chemical method mainly uses mild chemicals. Chemical cleaning is usually carried out by circulating the selected reagents through a filter system. The chemical solution is collected in a tank near to, or below, the surface being cleaned. From this tank, a spraying system circulates the solution between the surface and the tank. Decontamination can also be carried out by immersion of the contaminated item (hand tools, special parts of machinery) in a bath. There are two types of procedures: *static* (without flow) and *dynamic* (with flow). The dynamic method is useful for removing radionuclides from both internal and hidden surfaces.
Target	Contaminated industrial surfaces of plastic, ceramic, glass and coated surfaces in buildings and special parts of machinery (tools).
Targeted radionuclides	All radionuclides. Not short-lived radionuclides alone.
Scale of application	Medium scale in highly contaminated industrial areas.
Time of application	Maximum benefit if carried out shortly after deposition.
Constraints	
Legal constraints	Liabilities for possible damage to property. Possible regulations on use of chemicals.
Environmental constraints	Chemical incompatibility. For example, if the system to be decontaminated previously contained chemicals, this material can produce some explosive gases when put together with the decontamination chemical.
Effectiveness	
Reduction in contamination on the surface	90 – 99 % reduction.
Reduction in surface dose rates	No estimates made. However, reductions in external dose rate above the surface should be similar to those above.
Reduction in resuspension	N/A
Technical factors influencing effectiveness	Treatment temperature (usually in the range of 20 – 90 °C). Concentration (pH). Flow rate (of the applied chemical solution) for the dynamic procedure. Contact time. Less effective on porous surfaces. Consistency in procedure application. The bottom part of the building should be cleaned particularly well, as this will often be the closest to people working in the building.
Social factors influencing effectiveness	None
Feasibility	
Equipment	High pressure water washer. Spray machines. Other hand tools (sponge, brush, cloths). Liquid tanks.
Utilities and infrastructure	Transport vehicles for equipment. Scaffolding or mobile lifts for tall buildings. Water supply. Pressurised air supply.
Consumables	Depends on the chemical resistance of target surfaces. Chemicals: cleaning detergents, chemicals such as detergent with complexing agents.
Skills	Skilled personnel required. Knowledge and experience in corrosion technology, waste generation/removal techniques and chemical cleaning is needed. Industrial cleaning companies will have the required skills.
Safety precautions	Safety helmets. Lifelines. Water proof safety clothing. Respiratory protection.

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55 Chemical cleaning of plastic and coated surfaces

	Proper ventilation (tanks are usually open to the air).
Waste	
Amount & Type	5 – 30 l m^{-2} liquid waste (applying a recycling system). Efficient recycling of reactive chemicals will help to keep waste levels low.
Doses	
Averted doses	Not estimated.
Factors influencing averted dose	Amount of time spent in or close to the building. Amount of the building that is covered in plastic or coated surfaces. Extent of decontamination of nearby surfaces.
Additional doses	Relevant exposure pathways for workers are: external exposure from radionuclides in the environment and contaminated equipment enhanced resuspension leading to inhalation of dust Exposure routes from transport and disposal of waste are not included.
Intervention costs	
Operator time	2 – 6 m^2/ team hr. Variable time for setting up scaffolds/transport.
Factors influencing costs	Need for scaffolding /mobile lifts. Different types of treatment of surfaces and waste chemicals. Cost of specialist labour. Cost of chemicals.
Side effects	
Environmental impact	Disposal or storage of waste. Should be minimised through the control of any disposal route and relevant authorisations. Electronic parts may be damaged by water if not dismounted. Damage to equipment due to the mechanical impact. If strong chemicals are used they may lead to corrosive and toxic reagents being produced which will need to be handled and disposed of.
Social impact	Acceptability of disposal of contaminated waste and chemicals. Reassurance of employees & users and maintaining continuity of work. Removal of coatings from surfaces may have negative effect on appearance of surfaces.
Practical experience	Used in small-scale at Nuclear Power Plants in normal practice. Tested in a number of industrial buildings in the Former Soviet Union and Europe after the Chernobyl accident.
Key references	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) (2000). *Compendium of measures to reduce radiation exposure following events with not insignificant radiological consequences.* Bonn: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, vols 1 and 2. Eged K, Kis Z, Andersson KG, Roed J and Varga K (2003). Guidelines for planning interventions against external exposure in industrial area after a nuclear accident. Part 1: a holostic approach to countermeasure application. GSF-Bericht 01/03, Germany. International Atomic Energy Agency (IAEA) (1989). *Cleanup of large areas contaminated as a result of a nuclear accident.* Vienna: International Atomic Energy Agency, Technical Report Series No. 300. Magyar Szabvány (1983). *Testing of painted coatings in the laboratory, determination for ease of decontamination.* Hungarian Patent Office: Hungarian Patent, No. MSZ-05 22.7662-83.
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56 Cleaning of contaminated (industrial) ventilation systems

Objective	To reduce external doses arising from contamination in ventilation systems in industrial buildings.
Other benefits	Removal of contamination from the area and prevent redistribution of contamination in buildings.
Management option description	The Chernobyl accident demonstrated how industrial ventilation systems may become heavily contaminated and are not very easy to decontaminate. Cleaning involves industrial vacuum cleaning, washing with chemical solutions and possibly the use of an electrical rotating brush in narrow ventilation ducts. In channels with larger diameters (> 50 cm) it is often necessary for a person to enter the duct with a 'NORCLEAN' type industrial vacuum cleaner. Alternatively, it may be possible to open the ventilation system and hose it at high pressure with water.
Target	Highly contaminated (industrial) ventilation systems.
Targeted radionuclides	All radionuclides. Not short-lived radionuclides alone.
Scale of application	Could be carried out on a medium scale in highly contaminated industrial areas.
Time of application	Maximum benefit if carried out shortly after deposition. Can have a significant effect on reducing contamination levels even if applied a decade after contamination.
Constraints	
Legal constraints	Liabilities for possible damage to property. Possible regulations on chemical use.
Environmental constraints	None
Effectiveness	
Reduction in contamination on the surface	**High pressure hosing:** 80 - 97 % reduction in contamination. **Vacuuming/brushing:** 80 - 90 % reduction in contamination.
Reduction in surface dose rates	Not estimated.
Reduction in resuspension	
Technical factors influencing effectiveness	The physico-chemical form of the aerosol (e.g. size, solubility). Operator skills. Pressure and amount of water for high pressure water treatment. Water temperature: because the air outlet channels, in particular may be greasy and contain dust; a high water temperature (>60 ºC) is required to ensure a high reduction in contamination levels. However, it should be noted that the inlet channels are usually the most contaminated.
Social factors influencing effectiveness	None
Feasibility	
Equipment	Brushes. Vacuum device. 'Dust trap' filter and/or 'NORCLEAN' type industrial vacuum cleaner and/or high pressure water washer. Grinding machines. Other hand tools.
Utilities and infrastructure	Transport vehicles for equipment. Scaffolding or mobile lifts for tall buildings, where channels may be mounted under the ceiling.
Consumables	Water supply. Pressurised air supply.
Skills	Skilled personnel required. Industrial cleaning companies will have the required skills.
Safety precautions	Lifelines. Safety helmets. Waterproof safety clothing. Respiratory protection.
Waste	
Amount & Type	**Solid waste:** 50 – 100 g per m^{2} (Solid waste contamination level:~ 10 – 20 kBq m^{-3} per Bq m^{-2}). **Dry waste:** is collected in vacuuming filters that are relatively easy to dispose. **Liquid waste:** from pressure washing can mostly be collected and filtered with the industrial vacuum cleaner, so that the water is cleaned and sludge is left.

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56 Cleaning of contaminated (industrial) ventilation systems

Doses	
Averted doses	Not estimated.
Factors influencing averted dose	Amount of time spent in the vicinity of ventilation ducts.
Additional doses	Relevant exposure pathways for workers are: external exposure from radionuclides in the environment and contaminated equipment enhanced resuspension leading to inhalation of dust The dose over a day to a worker implementing decontamination of ventilation ducts may be significantly higher than that to an individual living or working in the contaminated area. This is due to the very high contamination levels that can build up in ventilation systems (especially in filters). The level of contamination depends on the size of filter and filter system (i.e. requirement to climb into system or possibility for external handling). Dose rates must be assessed prior to any time-consuming action.
Intervention costs	
Operator time	**Small channels:** (<20 cm in diameter): 6 m^2 per hour. **Larger channels:** 2 – 3 m^2 per hour. If there are valves, these must be dismounted. Each valve takes about 1.5 h to dismount.
Factors influencing costs	Need for scaffolds /mobile lifts. Need for different types of treatment (dependant on e.g., channel sizes and other ventilation system characteristics). Cost of specialist labour.
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations. Electronic parts may be damaged by water if not dismounted.
Social impact	Acceptability of disposal of contaminated waste. Removal of the corrosion products from the surface. Reassurance of employees and users and maintaining continuity of work.
Practical experience	Tested in a number of industrial buildings in the Former Soviet Union and Europe after the Chernobyl accident.
Key references	Eged K, Kis Z, Andersson KG, Roed J and Varga K (2003). Guidelines for planning interventions against external exposure in industrial area after a nuclear accident. Part 1: a holostic approach to countermeasure application. GSF-Bericht 01/03, Germany. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). *Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3.
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57 Electrochemical cleaning of metal surfaces

Objective	To reduce external doses arising from contamination on metal surfaces, particularly machinery and tools in industrial buildings.
Other benefits	Removal of contamination from machinery and tools and prevent redistribution of contamination in buildings.
Management option description	A chemical decontamination, assisted by an electrical field. It uses a direct electric current, which results in the anodic dissolution and removal of metal and oxide layers. These in-situ processes may only be applied for removing radionuclide contamination from conducting surfaces, such as iron-based alloys (including stainless steel), copper, aluminium, lead and molybdenum. They are highly effective. Can be applied by immersion of the contaminated item in an electrolyte bath or by passing a pad over the surface to be decontaminated. The electrolyte is continuously regenerated by recirculation. The chemicals that can be used and their applicability for different surfaces are given under the consumables section below.
Target	Contaminated (industrial) metal surfaces forming special parts of machinery and hand tools. It is not effective for decontamination of welds.
Targeted radionuclides	All radionuclides. Not short-lived radionuclides alone.
Scale of application	Very small scale in highly contaminated industrial areas.
Timing of implementation	Maximum benefit if carried out shortly after deposition.
Constraints	
Legal constraints	Liabilities for possible damage to property. Possible regulations on use of chemicals.
Environmental constraints	None
Effectiveness	
Reduction in contamination on the surface	Almost 100 % reduction.
Reduction in surface dose rates	No estimates made.
Reduction in resuspension	No estimates made.
Technical factors influencing effectiveness	Removal of coatings such as oil, grease, oxides, paint etc. before decontamination. Important operating parameters include: electrolyte composition and concentration, operating temperature, contact time, electrode potential and current density, construction of electropolishing system (homogeneity of the current and potential fields). The in-situ process is limited by the size of the bath when immersion is used, and by the geometry of the surfaces and the available free space around the part being treated when a pad is used (less applicable for complex geometries). Effectiveness may be improved by increasing the concentration of the applied chemical solution. The electropolishing does not remove (or removes with difficulty) nuclear fuel fines (hot particles) from the surface. Consistency in procedure application.
Social factors influencing effectiveness	None
Requirements	
Equipment	Electropolishing system with recirculation. 2 tanks (One contains the electrolyte, electrodes and structural or other parts to be decontaminated; the other holds the water used for rinsing the parts after decontamination). Provisions for heating & agitating the electrolyte. A special movable pad is needed as an electrode for delivering the current to the submerged component being decontaminated. An extraction hood to control vapour release from the electrolyte.
Utilities and infrastructure	Transport vehicles for equipment. Water and power supplies.
Consumables	Chemical materials, typically used as electrolytes: phosphoric acid (T= 40 – 80°C, electrode potential 8 – 12 V, current density 60 – 270 mA/cm^2), because of its stability, safety and applicability to a variety of alloy systems nitric acid (T= 10 – 35°C, electrode potential 5 – 8 V, current density 400 – 2000 mA/cm^2), good results on welded surfaces too organic acid (T= 20 – 40°C, electrode potential 15 – 24 V, current density 200 mA/cm^2), organic acid processes have good pH stability, resisting pH changes resulting from hydroxide formation. **Passivation*:*** nitric acid (HNO_3) or phosphoric acid (H_3PO_4) or sulphuric acid (H_2SO_4) or

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57 Electrochemical cleaning of metal surfaces

	hydrogen peroxide (H_2O_2).
Skills	Skilled personnel required who are trained in electrochemical techniques.
Safety precautions	Safety helmets. Waterproof safety clothing. Respiratory protection Proper ventilation
Waste	
Amount & Type	5 – 15 l m^{-2} liquid waste. Efficient recycling of reactive chemicals will decrease the amount of waste produced. If organic acids are used, the destruction of the organic acid component yields non-acidic waste.
Doses	
Averted doses	Not estimated.
Factors influencing averted dose	Amount of time spent in or close to the buildings. Amount of the building that is covered in metal surfaces. Extent of decontamination of nearby surfaces.
Additional doses	Relevant exposure pathways for workers are: external exposure from radionuclides in the environment and contaminated equipment enhanced resuspension leading to inhalation of dust Acid must to be exchanged or regenerated periodically. Handling the parts to be immersed or the pad may lead to additional exposure to workers.
Intervention costs	
Operator time	5 – 20 min. to remove contamination from the surfaces. The pre-treatment and the passivation of the surfaces will take some hours.
Factors influencing costs	Access to surfaces. Process use. Cost of specialist labour. Cost of chemicals.
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations. In the case of phosphoric acid processes, airborne contamination is minimised and the complexing characteristics minimise the recontamination. High current densities tend to produce excessive oxygen (which may be dangerous and potentially cause an explosion). The thickness of metal removed during decontamination is generally less than 5 mm (new techniques) therefore the surface is not substantially damaged. Corrosion problems may occur. The main sources of corrosion problems are selective corrosion as a consequence of the selective dissolution processes of the alloying components of decontaminated metals and lack of perfect passivation of the surface following the decontamination procedure.
Social impact	Acceptability of disposal of contaminated waste. Reassurance of employees & users and maintaining continuity of work. Removal of the corrosion products from the surface; the metal surfaces are cleaned.
Practical experience	Widely applied at Nuclear Power Plants during normal practice and decommissioning.
Key references	Eged K, Kis Z, Andersson KG, Roed J and Varga K (2003). Guidelines for planning interventions against external exposure in industrial area after a nuclear accident. Part 1: a holostic approach to countermeasure application. GSF-Bericht 01/03, Germany. Metal Coating Process Corporation (2002). *An overview and general process steps of electropolishing.* Charlotte, NC: MCP Corporation. Available online at: http://www.electropolish.com/master.htm [Accessed on 16/10/08] Nuclear Energy Agency (NEA) (1999). *Decontamination techniques used in decommissioning activities.* NEA Report-1707. Available online at: http://www.nea.fr/html/rwm/reports/1999/decontec.pdf [Accessed 16/10/08] US Department of Energy (1994). *Decommissioning technology descriptions: decontamination.* USDoE, Office of Environmental Management.
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58 Filter removal

Objective	To reduce external doses arising from contamination in filter systems in industrial buildings and commercial vehicles.
Other benefits	Removal of contamination from the area and prevent redistribution of contamination in buildings.
Management option description	A significant quantity of radioactivity may be removed by exchanging the filters from industrial buildings, mainly from ventilation systems and other simple fans and heaters. In addition, the removal of the filter from vehicles (trucks, transport vehicles) can also be effective. Subsequent recontamination to an extent that requires repeated application is very unlikely.
Target	Highly contaminated (industrial) ventilation systems. May also be suitable for commercial vehicles.
Targeted radionuclides	All radionuclides. Not short-lived radionuclides alone.
Scale of application	Medium scale in highly contaminated industrial areas.
Time of application	Maximum benefit if carried out shortly after deposition. Can have a significant effect on reducing contamination levels even if applied a decade after contamination.
Constraints	
Legal constraints	Liabilities for possible damage to property.
Environmental constraints	None
Effectiveness	
Reduction in contamination on the surface	Expected reduction up to 100 %.
Reduction in surface dose rates	No estimates made.
Reduction in resuspension	No estimates made.
Technical factors influencing effectiveness	Filter contamination. Filter position. Type of the filter. Filter housing design.
Social factors influencing effectiveness	None
Feasibility	
Equipment	Dependent on the type of filter system. Ventilation systems and vehicles may require different types of hand tools to be used.
Utilities and infrastructure	Transport vehicles for equipment. Scaffolding or mobile lifts for tall buildings. Power supply.
Consumables	None
Skills	Skilled personnel required.
Safety precautions	Lifelines. Safety helmets. Waterproof safety clothing. Respiratory protection.
Waste	
Amount & Type	Filter (solid).
Doses	
Averted doses	Not estimated, although reductions in dose rates to drivers of vehicles are likely to be higher than those to people working in buildings due to their proximity to the filters.
Factors influencing averted dose	Amount of time spent in the vicinity of ventilation systems, fans or heaters.
Additional doses	Relevant exposure pathways for workers are: external exposure from radionuclides in the environment and contaminated equipment enhanced resuspension leading to inhalation of dust Exposure routes from transport and disposal of waste are not included. The dose over a day to a worker implementing decontamination may be significantly higher than that to an individual living or working in the contaminated area because very high contamination levels can build up in ventilation systems, especially in filters. Dose rates must be assessed prior to any time-consuming activities.
Intervention costs	

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58 Filter removal

Operator time	Between a few minutes & a few hours per filter, depending on the type.
Factors influencing costs	Need for scaffolding /mobile lifts. Different types of filter and access depending on ventilation system. Cost of specialist labour.
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations. Electronic parts may be damaged by water if not dismounted. Damage to equipment due to mechanical impact.
Social impact	Acceptability of disposal of contaminated waste. Removal of the corrosion products from the surface; the ventilation system is cleaned, and is expected to run better. Reassurance of employees & users and maintaining continuity of work.
Practical experience	Tested in a number of industrial buildings in the Former Soviet Union and Europe after the Chernobyl accident.
Key references	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) (2000). *Compendium of measures to reduce radiation exposure following events with not insignificant radiological consequences.* Bonn: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, vols 1 and 2. Eged K, Kis Z, Andersson KG, Roed J and Varga K (2003). Guidelines for planning interventions against external exposure in industrial area after a nuclear accident. Part 1: a holistic approach to countermeasure application. GSF-Bericht 01/03, Germany.
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59 Ultrasound treatment with chemical decontamination

Objective	Reassurance of the industry workforce.
Other benefits	Reduction in external and skin contact doses arising from contamination on metal objects used in industry. Will clean tools and objects.
Management option description	Based on the use of ultrasonic waves in a bath containing a cleaning solution. The ultrasound is produced by a generator at a frequency greater than 20 kHz. A transducer converts high frequency energy into low amplitude vibrations at the same frequency. Scrubbing is accomplished through the formation and violent collapse of thousands of minute bubbles, which lift radionuclides from the object's surface. Ultrasonic decontamination (with chemicals) requires efficient recycling of reactive chemicals to minimise secondary waste production, which may be difficult to treat. Repeated application may be necessary if the tools subsequently become contaminated.
Target	Contaminated (industrial) metallic hand tools kept indoors or outdoors. Only likely to be used for valuable items or items that are not easy to replace. Not recommended for concrete or plastic.
Targeted radionuclides	All radionuclides. Not short-lived radionuclides alone.
Scale of application	Suitable for use on a small scale.
Time of application	Maximum benefit if carried out shortly after deposition.
Constraints	
Legal constraints	Liabilities for possible damage to property. Possible regulations on chemical use.
Environmental constraints	None
Effectiveness	
Reduction in contamination on the surface	90 – 99 % reduction in contamination on metal surfaces.
Reduction in surface dose rates	Not estimated.
Reduction in resuspension	
Technical factors influencing effectiveness	Frequency of the generator. Age of the contamination. Solvent processing sub-system: solvent filtration for removal of the radioactive particles, temperature control, and solvent recovery.
Social factors influencing effectiveness	None
Feasibility	
Equipment	Ultrasonic vibrator (generator) and vibratory tank. Bath. Transport vehicles for equipment.
Utilities and infrastructure	Power supplies. Roads for transport of equipment, materials and waste.
Consumables	Fuel for transport vehicles. Cleaning solutions (e.g. Alconox or Contrad).
Skills	Skilled personnel required.
Safety precautions	Waterproof clothing. Gloves and safety glasses. Respiratory protection. Ventilation must be installed because the baths are usually open to air.
Waste	
Amount & Type	*Amount:* Depends on the size of the tank. The treatment (filtration) and conditioning of this waste requires appropriate processes to be available when selecting the decontamination option. *Type:* Waste water.
Doses	
Averted doses	No estimate made. Main purpose is for reassuring the workforce.
Factors influencing averted dose	Amount of time spent using the tools.
Additional doses	Relevant exposure pathways for workers are: external exposure from radionuclides in the environment and contaminated equipment enhanced resuspension resulting in inhalation of dust

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59 Ultrasound treatment with chemical decontamination

	Exposure routes from transport and disposal of waste are not included.
Intervention costs	
Operator time	Generally 10 – 90 min. per treatment but will depend on the number of articles in a tank.
Factors influencing costs	Type of equipment used. Method for treatment of waste.
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	Acceptability of disposal of contaminated waste. Removal of the corrosion products from the surface. Reassurance of employees and users. Work continuity.
Practical experience	Used at a small-scale at nuclear power plants in normal practice and in radiochemical laboratories.
Key references	Eged K, Kis Z, Andersson KG, Roed J and Varga K (2003). Guidelines for planning interventions against external exposure in industrial area after a nuclear accident. Part 1: a holostic approach to countermeasure application. GSF-Bericht 01/03, Germany. Fuchs FJ (2002). *Ultrasonic cleaning: fundamental theory and application.* Jamestown, NY: CAE Ultrasonics. Available online at: http://www.caeultrasonics.com/fu-page1.php3 [Accessed 15/10/08]. US Department of Energy (1994). *Decommissioning technology descriptions: decontamination.* USDoE, Office of Environmental Management.
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4 FACTORS INFLUENCING IMPLEMENTATION OF MANAGEMENT OPTIONS

There are a number of factors that need to be taken into account when developing a management strategy for the long term recovery of a contaminated inhabited area. The most important of them are:

- temporal and spatial factors
- effectiveness of management options
- protection of workers
- waste disposal issues
- societal and ethical aspects
- environmental impact
- economic cost
- communication and information issues

Each factor is considered in more detail in the following sections.

4.1 Temporal and spatial factors

The consequences of a radiological incident depend on the time of the release. If the release occurred in the middle of the night, fewer people are likely to be outside and directly contaminated.

Some radionuclides decay very quickly, whereas others can stay in the environment for decades; in addition radionuclides will transfer from the location where they deposit because of weathering. The time since the release of radioactivity can therefore be of great importance, depending on the radionuclides involved. Furthermore, the spread of contamination in the area will increase over time causing a change in activity concentrations of radionuclides over time.

The type of area affected and its location and size can have an impact on the choice of management options. Area size affects the speed with which a recovery strategy can be implemented, what it entails and the timescale on which it can be completed. Small areas of contamination may be more easily cleaned than large areas and more options may be practicable. Furthermore the type of area and its location are important factors. If a residential area with high numbers of inhabitants is contaminated, there will be a great pressure from the public to ensure that it is still safe to live there and send children to school or play in the parks. If the location of an incident affects priorities which may be linked to tourism, political sensitivities, economic stability or critical facilities and infrastructure, there will also be increased pressure to minimise contamination promptly.

4.2 Effectiveness of management options

As mentioned in Section 1, the primary aim of most of the management options considered in this Handbook is to reduce external doses from deposited radionuclides and inhalation doses from resuspension of contaminated material.

The effectiveness of management options is influenced by technical and societal factors, some of which are very specific to one or two options. Comprehensive guidance on effectiveness is provided on individual datasheets (Section 3).

4.2.1 Effectiveness of shielding options

The **effectiveness of a shielding option** is defined as the reduction in the external dose rate from a surface (e.g. buildings, paved surfaces, grass, soil, and shrubs), generally expressed as a percentage, after the implementation of the option.

The effectiveness of shielding provided by an option depends on the radionuclides present and the thickness of the shielding material. The effectiveness of different shielding options is included in the relevant datasheets (Section 3). Estimates have also been made of the typical thicknesses of materials that would be required to reduce gamma dose rates by factors of two and ten. The thicknesses can be applied to a range of normal solid materials that could be used for shielding in an inhabited area, ranging from wallpaper to concrete, and are given in Table 4.1 for three gamma energy bands (< 0.1 MeV, 0.1 – 1.0 MeV, > 1 MeV). All thicknesses are approximate values and should be used for scoping calculations only. The thicknesses are only appropriate for materials with densities up to about 2500 kg m^{-3}. Table 1.1 provides the gamma energy of all radionuclides considered by the Handbook. For other radionuclides, this information can be found in an ICRP publication (ICRP, 1983). It should be stressed that this approach has been developed for materials most likely to be practicable within contaminated areas. It is recognised that other materials such as lead provide the best shielding against gamma emitting radionuclides; however, their use is unlikely to be practicable on medium or large scale in inhabited areas.

The reductions in beta dose rate that could be expected from the use of shielding materials within inhabited areas are given for ^{90}Sr in Table 4.2 (this radionuclide has a high energy beta emitting daughter radionuclide, ^{90}Y). For radionuclides emitting weak beta radiation[1] (see Table 1.1) shielding will be very effective in reducing external dose rates from the surface.

Table 4.1 Material thickness required to reduce external gamma dose rates by a factor of two and ten as a function of gamma energy

		Thickness of material (cm)	
Energy range*	Radionuclides	Reduction factor of 2	Reduction factor of 10
Low energy (< 0.1 MeV)	^{238}Pu, ^{239}Pu, ^{241}Am	< 5	< 20
Medium energy (0.1 – 1 MeV)	^{75}Se, ^{95}Zr, ^{95}Nb, ^{99}Mo, ^{103}Ru, ^{106}Ru, ^{131}I, ^{132}Te, ^{134}Cs, ^{137}Cs, ^{169}Yb, ^{192}Ir, ^{235}U	< 10	Few 10s
High energy (> 1 MeV)	^{60}Co, ^{136}Cs, ^{140}Ba, ^{140}La, ^{144}Ce, ^{226}Ra	Few 10s	Few 10s - 100

Notes:

*: The energy with the highest probability of emission has been used. The energies of daughter radionuclides have been taken into account. Energies were taken from ICRP, 1983.

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[1] For the purposes of the Handbook, a weak beta emitter has a maximum energy of less than 2 MeV.

4.2.2 Effectiveness of shielding options - fixing options

The **effectiveness of a fixing option** is defined as the reduction in the inhalation dose from reducing resuspension of contaminated material from a surface (e.g. buildings, paved surfaces, grass, soil, and shrubs), generally expressed as a percentage, after implementing the option.

Possible fixing options considered for each surface are given in Table 4.3 along with the possible benefits for the radionuclides under consideration in the Handbook. It should be noted that fixing options are sometimes also known as tie-down options. The primary aim of fixing options is to reduce the intake of contamination into the body, for example, by inhalation. These options can also provide some shielding from the contamination and hence reduce external dose rates. An indication of how effective fixing options may be in reducing external dose rates is also given in Table 4.3. Values provided in the table are for ^{90}Sr and its daughter ^{90}Y. These radionuclides have been chosen as they emit high-energy beta radiation. For many beta emitting radionuclides, the reductions in dose rate will be greater. Values in the table are approximate and should only be used for scoping the effectiveness of fixing material as shielding media. Most fixing options provide very little protection against gamma emitting radionuclides. If soil, sand or bitumen are used as a fixing material, there are some benefits in terms of reducing external dose rates above the contaminated surface, as shown in Table 4.3.

Fixing can be either temporary or permanent, depending on the material used, as specified in Table 4.3. In the table it was assumed that fixing methods are of benefit if reductions in doses of more than 30% can be achieved. Temporary fixing options are only likely to be effective for a day or so, after which their integrity is likely to be compromised unless the application is repeated. Permanent fixing options remain in place until they are subsequently removed (e.g. bitumen coatings on roads), although it should be noted that all fixing materials are likely, to some extent, to lose integrity over time and become less effective. Fixing options considered in this Handbook are unlikely to be suitable for specialised building surfaces. Water is expected to be used only to dampen the surface prior to removal to reduce inhalation doses to workers arising from material resuspended during the removal. For contaminated soil, water also has the benefit of aiding the bonding of activity to the soil particles and can wash the contamination below the surface of porous soils, both of which actions reduce long-term resuspension. However, it should be noted that resuspension often does not contribute significantly to doses and that radioactive material washed off grass or plants produces higher activity concentrations in the soil. For roads and paved areas, water is also likely to wash some contamination off the surface into the drains or onto neighbouring soil and grass surfaces. It should be noted that, soil could also be used to cover material on roads and paved areas. Such thin layers are potentially disturbed by vehicles, pedestrians, wind and other means. Sand and soil on roads can interfere with rainwater run-off gulleys, unless given special attention.

Table 4.2 Effectiveness of some fixing options in reducing external beta dose rates for beta emitters

	Reductions in external beta dose rate above the surface while shielding material is in place	
Fixing option	Thickness of material* (mm)	Dose rate reduction above surface (%)
Paint on external building surfaces	1	45
Water on roads and paved areas	1	45
Sand on roads and paved areas	2	90
Bitumen on roads and paved areas	1	70
Soil on outdoor ground surfaces	50	100
Peelable coatings on outdoor hard surfaces	2	65

Note:

*: Thickness of materials assumed are those stated in the datasheets (Section 3)

Table 4.3 Protection provided by implementation of fixing options for contaminated outdoor surfaces in inhabited areas

Fixing option	Protection against inhalation of resuspended material	Protection against external gamma	Protection against external beta
Paint on external building surfaces (T/P)*	Yes	No	Yes
Water on roads and paved areas (T)	Yes	No	Yes
Water on soil, grass and plant surfaces (T)	Yes	No	No
Sand on roads and paved areas (T)	Yes	No	Yes
Bitumen on roads and paved areas (T/P)	Yes	No	Yes
Soil on outdoor ground surfaces (T/P)	Yes	Yes	Yes
Peelable coatings outdoor hard surfaces (T)	Yes	No	Yes

Keys: T = temporary; P = permanent

Note:

*: Paint could also be considered for indoor surfaces. Similarly, laying carpet or wallpapering would also fix.

4.2.3 Effectiveness of removal options

The **effectiveness of a removal option** is defined as the ratio of the activity initially present on a specific surface (e.g. buildings, paved surfaces, grass, soil, and shrubs) to that remaining after implementing the option. This ratio is usually called the Decontamination Factor (DF).

A DF of 5, for example, means that 80% of the activity on the surface can be removed by a particular technique. It should be noted that the DF is only a measure of the efficiency of a technique in removing activity from a specific surface; it is not a measure of the reduction in the overall exposure from deposited material on all surfaces in the environment where an individual resides.

In cases where the contamination can penetrate significantly into a surface, such as soil, the use of a DF is not, in general, appropriate. Instead, the reduction in the dose rate at a reference height above the surface (typically 1 m), after the partial or total removal of contamination to a given depth, is used to express the effectiveness of implementing a particular option on that surface.

For hard surfaces, it is reasonable to assume that much of the activity on the surface is available for resuspension and, therefore, techniques that remove contamination from the surface also reduce the resuspended activity in air from that surface. For permeable surfaces, such as soil, it is generally accepted that only the surface layer of the soil (typically 10 mm deep) contributes to the resuspended activity. The reduction in activity in the surface layers of the soil following the implementation of removal options is therefore an important measure of the possible reduction in resuspension and the resultant concentration in air will be reduced by the value of the DF.

All values of DF, reductions in dose rate above the surface, and reductions in resuspension presented in this Handbook should be treated as indicative only. The actual values achieved greatly depend on the specific circumstances of the incident. In the event of a radiological emergency, it may be necessary to trial the proposed technique on a small part of the area to be decontaminated, in order to determine more accurately the effectiveness that could be expected.

4.2.4 Social factors affecting the effectiveness of management options

The effectiveness of management options is influenced by a wide array of social factors including the ability of authorities to control the movement of people in and out of contaminated areas and their compliance with instructions and advice; people cannot be forced to comply, may not understand the instructions or be able or willing to follow them.

4.3 Protection of workers

Workers can be divided into two groups: members of the public who work in the area or who come into the affected area to work, termed normal workforce, and people implementing the recovery strategy, including clean-up, monitoring and other operations.

4.3.1 Workers implementing a recovery strategy

If workers implementing management options are subjected to additional risks, these should be taken into account in the justification and optimisation of the recovery strategy (ICRP, 2007). Persons involved in recovery operations should be subject to the normal system of radiological protection for occupational exposure (see Table 4.4) as their work can be planned and their exposure controlled (ICRP, 2007). This system of dose limitation also applies to the handling and disposal of any wastes produced during the implementation of recovery actions.

Table 4.4 Dose limits for practices for workers and the public

Category	Effective dose (mSv y^{-1})	Skin dose (mSv y^{-1})	Lens of eye (mSv y^{-1})
Workers	20	500	150
Members of the public	1	50	15

4.3.2 Types of specific worker risks

Radiation risks to workers will particularly be related to external exposure to contamination in the environment, external exposure from radioactive contamination on the body, and internal exposure from inhalation of resuspended radioactive substances.

A number of protective measures may be chosen to reduce the risks to workers, according to the requirements in the specific situation. Such measures include: delaying implementation of management options; work time restrictions; shielding; ventilation; fixation; respiratory protection; protective tight fitting safety glasses; and protective clothing.

Use of protective equipment should be optimised for the task. Excessive, unnecessary and clearly visible worker protection may contribute to the anxiety of local inhabitants of the area; therefore its use should be justified. Safety precautions are discussed, in general terms, for each management option in the datasheets (see Section 3).

4.4 Disposal of radioactively contaminated waste

The contamination of an inhabited area following a radiological incident generates both solid and liquid radioactive waste regardless of whether any recovery strategy is implemented. Three categories of radioactive waste are considered in this Handbook:

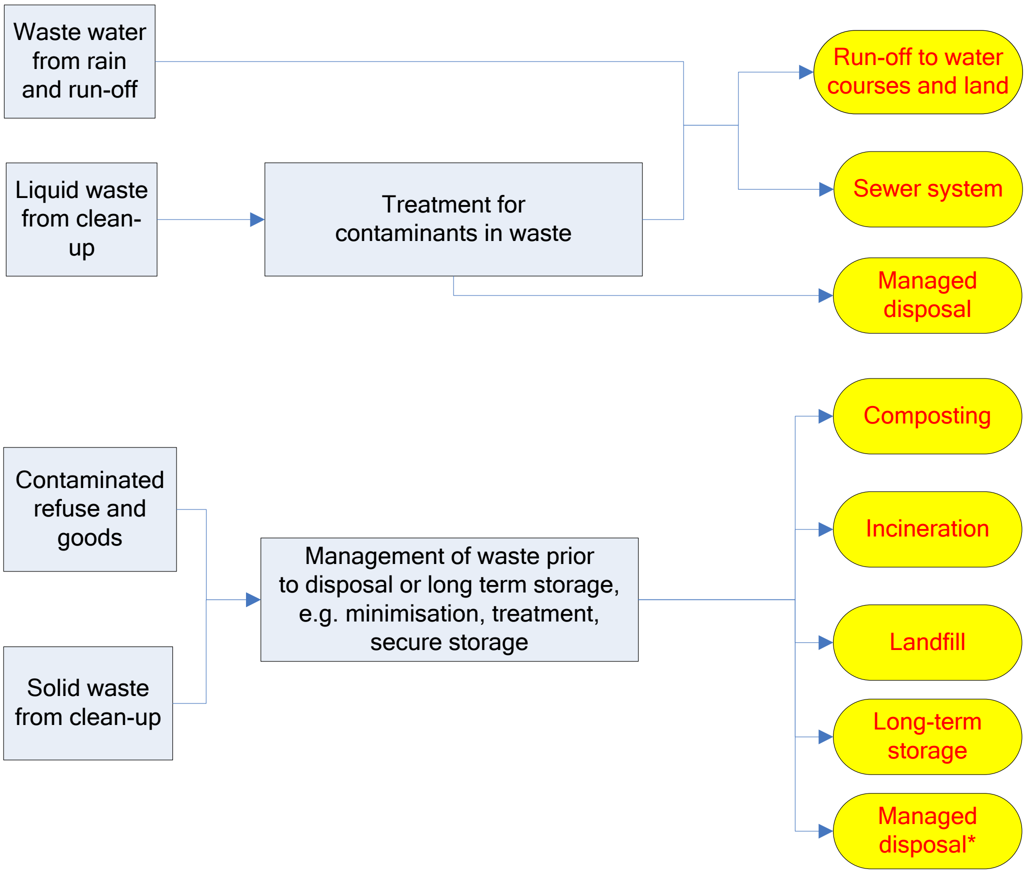
- contaminated waste (refuse) and goods;
- waste from clean-up of the contaminated area (solid and liquid);
- waste water from rainfall and natural run-off.

It is therefore important to consider the impact of the contaminated waste on the public, workers handling the waste, the environment and normal waste disposal practices. Figure 4.1 illustrates an overview of the waste management routes for solid and liquid waste contaminated with radioactivity.

4.4.1 Categorisation of contaminated waste

Each European country has derived its own characterisation system for contaminated wastes arising from practices, according to a number of ranges of specific activity (e.g. intermediate, low and very low). Whilst there is no common classification system for member States, clearance levels have been suggested, below which the contamination in the waste gives rise to trivial levels of dose (IAEA, 1996). These could be used to define categories of waste that can be disposed of via normal disposal routes.

Figure 4.1 Waste management routes



*Managed disposal = disposal via authorised routes (e.g. Drigg or future deep geological disposal)

4.4.2 Management of solid and liquid waste arising from clean-up

A number of management options generate radioactive waste. Any decision to undertake clean-up which generates radioactive waste should be supported by an assessment of the impact that the generated waste will have on the public, workers and the environment and considerations on the method of disposal of the waste. This assessment involve an estimation of the activity levels in the waste, an estimation of the quantities of waste produced and an assessment of the exposures to workers and public from the waste. Appendix C contains more information on the management of solid and liquid waste from clean-up. Estimates of the quantities of waste that could be expected from the implementation of clean-up options are indicated in the datasheets for each option (Section 3) and in Table 6.11. The selected waste disposal option will depend on the nature of the waste, the level of activity in the waste and the availability and acceptability of waste disposal routes.

In order to help identify if disposal of aqueous waste direct to sewers is likely to be a problem, estimates have been made of the likely contamination levels in the waste arising from clean-up options as a function of deposition level. The data are presented in Table 4.5. These data should be taken as illustrative only and monitoring would be required to demonstrate the actual contamination levels in any waste produced. It may be technically feasible to segregate the aqueous waste produced into contaminated dust/sludge and water. Depending on the radionuclide and its physical form in the waste, it may be possible to then dispose of the water without constraints. However, this is likely to be very expensive. Table 4.5 gives both activity concentrations in the total waste (dust + water) as well as likely concentrations in dust/sludge following filtering for the clean-up options producing aqueous wastes.

Table 4.5 Estimates of activity concentrations in liquid waste arising from clean-up as a function of deposition[a]

			Activity concentration per unit deposition (Bq kg^{-1} per Bq m^{-2})		
Clean-up option	Surface	Waste Material	^{137}Cs	^{131}I	^{239}Pu
Following wet deposition					
Fire hosing	Roads/paved	Water and Dust	3 10^{-1}	8 10^{-2}	2 10^{-1}
High Pressure Hosing	Roads/paved	Water and Dust	9 10^{-2}	2 10^{-3}	4 10^{-2}
		Dust sludge only	4 10^{1}	8 10^{-1}	2 10^{1}
Vacuum sweeping	Roads/paved	Water and Dust	1	2 10^{-1}	5 10^{-1}
Sandblasting	Roads/paved	Water and Dust	6 10^{-2}	1 10^{-3}	3 10^{-2}
		Dust sludge only	1 10^{-1}	3 10^{-3}	6 10^{-2}
Foam	Roads/paved	Aqueous waste + dust	2 10^{1}	5	1 10^{1}
Fire hosing	Buildings -external walls	Water and Dust	1 10^{-2}	5 10^{-3}	6 10^{-3}
		Dust sludge only	1	5 10^{-1}	6 10^{-1}
High Pressure Hosing	Buildings -external walls	Water and Dust	1 10^{-3}	5 10^{-5}	7 10^{-4}
		Dust sludge only	3	1 10^{-1}	1
Sandblasting	Buildings -external walls	Water and Dust	2 10^{-3}	6 10^{-5}	8 10^{-4}
		Dust sludge only	5 10^{-3}	2 10^{-4}	2 10^{-3}
Foam	Buildings -external walls	Aqueous waste + dust	6 10^{1}	3 10^{-1}	3 10^{-1}
Fire hosing	Buildings –external roofs	Water and Dust	2 10^{-1}	5 10^{-2}	8 10^{-2}
		Dust sludge only	8 10^{1}	2 10^{1}	3 10^{1}
High Pressure Hosing	Buildings –external roofs	Water and Dust	8 10^{-2}	2 10^{-3}	4 10^{-2}
		Dust sludge only	1 10^{2}	3	7 10^{1}
Sandblasting	Buildings –external roofs	Water and Dust	9 10^{-2}	2 10^{-3}	4 10^{-2}
		Dust sludge only	3 10^{-1}	6 10^{-3}	1 10^{-1}
Foam	Buildings –external roofs	Aqueous waste + dust	3 10^{1}	8	2 10^{1}
Following dry deposition					
Fire hosing	Roads/paved	Water and Dust	8 10^{-2}	3 10^{-2}	4 10^{-2}
High Pressure Hosing	Roads/paved	Water and Dust	2 10^{-2}	6 10^{-4}	8 10^{-3}
		Dust sludge only	7	3 10^{-1}	4
Vacuum sweeping	Roads/paved	Water and Dust	1 10^{-1}	6 10^{-2}	7 10^{-2}
Sandblasting	Roads/paved	Water and Dust	8 10^{-3}	3 10^{-4}	4 10^{-3}
		Dust sludge only	2 10^{-2}	6 10^{-4}	8 10^{-3}
Foam	Roads/paved	Aqueous waste + dust	3	1	2
Fire hosing	Buildings -external walls	Water and Dust	4 10^{-2}	2 10^{-2}	2 10^{-2}
		Dust sludge only	5	2	2
High Pressure Hosing	Buildings -external walls	Water and Dust	5 10^{-3}	2 10^{-4}	5 10^{-3}
		Dust sludge only	1 10^{1}	4 10^{-1}	9
Sandblasting	Buildings -external walls	Water and Dust	6 10^{-3}	3 10^{-4}	3 10^{-3}

Table 4.5 Estimates of activity concentrations in liquid waste arising from clean-up as a function of deposition[a]

Clean-up option	Surface	Waste Material	Activity concentration per unit deposition (Bq kg^{-1} per Bq m^{-2})		
			^{137}Cs	^{131}I	^{239}Pu
		Dust sludge only	2 10^{-2}	8 10^{-4}	9 10^{-3}
Foam	Buildings -external walls	Aqueous waste + dust	2	1	1
Fire hosing	Buildings –external roofs	Water and Dust	1 10^{-1}	8 10^{-2}	5 10^{-2}
		Dust sludge only	4 10^{1}	3 10^{1}	2 10^{1}
High Pressure Hosing	Buildings –external roofs	Water and Dust	4 10^{-2}	3 10^{-3}	4 10^{-2}
		Dust sludge only	8 10^{1}	5	7 10^{1}
Sandblasting	Buildings –external roofs	Water and Dust	5 10^{-2}	3 10^{-3}	2 10^{-2}
		Dust	1 10^{-1}	1 10^{-2}	7 10^{-2}
Foam	Buildings –external roofs	Aqueous waste + dust	2 10^{1}	1 10^{1}	1 10^{1}

a) Estimates of activity concentrations in waste calculated using CONDO (Charnock et al, 2003).

4.4.3 Management of contaminated waste (refuse) and goods

When no contamination is present, domestic and commercial refuse is normally sent to landfill or is incinerated. This may include a sorting stage, where the waste is manually sorted and suitable items are sent for recycling. Organic waste such as grass cuttings from gardens may be collected separately and sent to composting facilities. In the event of a radiological emergency, some refuse will be uncontaminated because it will have been placed in covered bins prior to deposition. Other refuse and garden waste collected after passage of the plume is likely to be contaminated. Some of the different factors requiring consideration for the management of domestic and commercial refuse following a radiological incident are outlined in Table 4.6. Responsibilities for handling the waste will depend on the levels of contamination present.

Table 4.6 Factors to consider for the management of domestic/commercial refuse

Household/commercial waste collection
Domestic and commercial refuse may be perceived by members of the public to be contaminated, even if it is not. A monitoring scheme should be put in place to enable release of waste that can be disposed of under normal practice (See Appendix C).
Delays in collection of household refuse may result in fly-tipping by the public and hence loss of control of the waste. Therefore, it is not generally acceptable to ask people to hold on to waste.
Temporary suspension of sorting and recycling of refuse should be considered.
Segregation of garden waste from other refuse should be considered if this is not normal practice.
If people are living as normal in an area, any specific precautions or differences in the way waste is collected may raise questions about the risks to the people living in the area.
Activity concentrations in the waste
Any covered, sealed or otherwise protected waste awaiting collection at the time of the release will not be contaminated, although, the containment or packaging itself may be contaminated.
Garden prunings may also be of concern if pruning is carried out in the first few months after deposition. Waste food from food grown in gardens and allotments in the contaminated area may have similar contamination levels to grass cuttings.
Activity concentrations in garden waste are likely to be in the order of 1 - 10 Bq kg^{-1} shortly after a deposition of

Table 4.6 Factors to consider for the management of domestic/commercial refuse

1 Bq m^{-2}. These concentrations will decrease with time due to natural weathering and removal of activity with garden waste. Activity concentrations in waste contaminated indoors will be significantly lower, probably at least 100 times.
Monitoring
A monitoring programme is needed to demonstrate that contamination levels in refuse meet disposal criteria and to support the segregation of wastes and subsequent disposal or storage if required.
Monitoring may be required to demonstrate that contamination levels in household refuse and in garden waste decrease with time.
Transport of waste
Transport of waste through uncontaminated areas may be unacceptable, although unavoidable.
Doses to workers involved in transport of waste should be assessed (see Appendix C).
Workers involved in refuse collection, transport and other activities
Risks to workers who normally collect refuse should be assessed as required (see Appendix C). These workers need to be able to be reassured that it is safe to handle the waste.
If people are living in an area then the external doses received by people working outdoors collecting refuse will be of the same order as those for someone spending time outdoors in that area. Contact doses should be controlled e.g. using of gloves. Use of specialist contractors should be considered as an alternative.
Temporary suspension of manual sorting should be considered.
Waste storage
Facilities to temporarily store waste prior to monitoring and selection of the appropriate disposal route need to be identified.
Storage facilities for radioactive waste are unsuitable for normal disposal. Local communities may not be willing to store waste in their area. Consider nuclear sites, site of incident, MoD sites, relocated areas (i.e. areas of high contamination where access is prohibited).
Would commercial premises with contaminated products (e.g. warehouses, supermarkets) be able to operate under the Radioactive Substances (Storage in Transit) Exemption Order (1962)? Authorisations may be required depending on levels of contamination.

4.4.4 Contaminated waste water: rain and natural run-off

Following the deposition of radioactivity by rainwater the subsequent natural run-off from an inhabited area is unlikely to be controllable. It is important therefore to have information to aid the assessment of the impact of this contaminated water. This will include likely doses to members of the public, doses to the workers involved in the management of waste water and the impact on the normal operation of sewage treatment works and practices for disposal of waste water. Table 4.7 contains information on possible destination routes for rainwater and run-off and also potential exposure pathways for members of the public. Rainwater may enter the sewer system, although this depends on the type of drainage system present. Many modern residential and industrial areas have separate rainwater run-off and foul water systems; in such cases, rainwater does not enter the sewers. Built-up areas may have combined systems which can allow rainwater to enter the sewer system. Properties in rural settlements are most likely to have combined systems, although some, particularly isolated dwellings, may have septic tanks. In the latter case, run-off water and rain will be directed to soak-aways. Septic tank drainage is not considered further in the Handbook. It should be noted that storm water may be handled differently to run-off under normal weather conditions.

Table 4.7 Rainwater routes and potential exposure pathways for members of the public

Rainwater route	Potential exposure pathways
Run-off from inhabited area surfaces enters water courses such as rivers	Use of watercourses for fishing, swimming, drinking water supplies or irrigation
Run-off enters sewers (foul water system)	Treated effluent from the sewage treatment works can be discharged into rivers or coastal waters Sewage sludge may be incinerated, send to landfill or spread on land.
Soak-aways (e.g. drainage from roofs via gutters and down-pipes into the ground)	Use of gardens for recreation, ingestion of food grown in gardens

As well as entering sewers, contaminated water may enter groundwater (e.g. leachates from landfill or from composting contaminated material) and contaminate drinking water supplies if water is obtained from such sources. Other drinking water sources will also have to be considered and potentially monitored (see Handbook for Drinking Water Supplies).

4.4.4.1 Estimates of activity concentrations in rainwater and run-off

A conservative estimate of the activity concentration in rainwater, if deposition has occurred through rainfall, is 1 Bq l^{-1} per Bq m^{-2} deposited (Brown *et al*, 2008). Run-off from buildings and other land surfaces in an inhabited area due to subsequent uncontaminated rainfall will remove very small quantities of contaminated material from the surfaces. The activity concentrations in the run-off water will be low and could be expected to be in the region of 1 10^{-3} Bq l^{-1} per Bq m^{-2} initially deposited for long-lived radionuclides (Charnock *et al*, 2003). Long term run-off is unlikely to be of concern for short-lived radionuclides.

Contaminated waste water may enter the sewage system depending on the drainage system. Appendix C contains information for situations where contamination has entered sewers and sewage treatment systems.

4.5 Societal and ethical aspects of the recovery strategy

4.5.1 Social considerations

Several studies have acknowledged the complexity and importance of social aspects when adopting a recovery strategy following a radiation incident (Alvarez and Gil, 2003; Hedemann-Jensen, 2003; Hunt and Wynne, 2002; OECD, 2004; Oughton et al., 2003). Despite the beneficial consequences of implementing management options some of the associated implications can decrease the quality of life of those affected. The implementation of management options are disruptive to normal social and economic life and may cause panic, stress or upheaval to those affected, possibly resulting in damage to health and well-being (Hedemann-Jensen, 2003). Those particularly susceptible are elderly people, parents with young families and pregnant women.

On the other hand, the implementation of management options may help provide reassurance to members of the public and workforce. They may also have a positive impact by making an area look cleaner than it was originally or improve the conditions of the infrastructures (e.g. improvements to the road and railway network). Local companies may be involved in the clean-up operations and thus may benefit financially. Failure to take positive action and carry out protective measures may also cause anxiety, often exacerbated by a lack of objective information (Hedemann-Jensen, 2003).

Many studies have emphasised the importance of engaging with stakeholders in order to assess the social implications of a recovery strategy (Hedemann-Jensen, 2003; Howard et al, 2005; Hunt and Wynne, 2002; Nisbet et al, 2005; OECD, 2004; Oughton et al, 2003). The involvement of stakeholders may take account of attributes other than those directly related to radiological protection (Hedemann-Jensen, 2003). The objective is that those concerned with the situation should be involved and given the opportunity to participate in the decision-aiding process under non-crisis conditions. Stakeholder involvement is an important component of the decision-making process, and in some cases it is essential for arriving at an accepted solution and for building trust in decision-making authorities (OECD, 2004). Within the radiological protection community, stakeholder participatory processes have moved steadily to the forefront of policy discussions, and clearly form key elements in decisions regarding the development and implementation of radiological protection policy (OECD, 2004). This position is consistent with ICRP recommendations which emphasise the importance of the involvement of stakeholders as an important input into optimisation (ICRP, 2007).

Societal factors which may influence the priorities given to a recovery strategy are listed in Table 4.8.

Table 4.8 Societal factors that may influence recovery priorities

Factor	Comments
Location	The location of a radiological emergency affects priorities, which may be linked to tourism, political sensitivities, economic stability or critical facilities and infrastructure.
Numbers of people affected	If large populations are affected, the impact for public health may be significant even if individual doses are not high. Similarly, the collective disruption caused by implementing management options will be high. There may be pressure to give priority to highly populated residential areas or areas where many people work compared with sparsely inhabited rural areas.
Are people living in the contaminated area? Have they been evacuated in the emergency phase?	Priority may be given to residential areas where people have not been evacuated. Subsequently, priorities within residential areas may be set based on predicted doses. Practicability of options and priorities within an area may be affected by people not having been relocated. If people have been evacuated it may be possible to extend the time that they are out of the affected area in order to implant the chosen options. Some management options require access to public areas to be temporarily restricted. In addition, restrictions may be placed on some public activities following completion of management options (e.g. digging beyond a certain depth will be forbidden). Such restrictions may not be practicable or publicly acceptable and this needs to be considered when developing a recovery strategy
Type of radiological emergency or incident	Incidents involving specific radioactive substances, such as plutonium, may lead to enhanced fear within the affected population and outside the affected area.
Economic stability. Need to keep businesses and infrastructure open.	Priorities may be biased towards commercial businesses, shops, roads, railways and other activities to ensure that the economy of the area is not unduly affected and to support people living in the area.
Return to life as normal. Need to keep critical facilities and infrastructure open.	Public or commercial facilities in the area which are considered critical may require high priority in any recovery strategy to ensure that they remain viable and safe. It is likely that additional burdens may be placed on public services (e.g.

Table 4.8 Societal factors that may influence recovery priorities

Factor	Comments
	schools and hospitals). Keeping schools and other public buildings open and allowing people to move freely in the affected area may become a priority in order to demonstrate life has returned to normal
Damage to personal property	Personal property and objects, amenities and objects of heritage may be damaged or contaminated following the implementation of management options.
Public perception of the affected areas from people living outside it	Public perception that the area is significantly contaminated can have profound social consequences. Industries and businesses may be affected as well as the identity of local communities and groups. It can be expected that tourists will not return to the affected area until the people have returned to living normally. It may take several years before the tourism industry is restored to the area, depending on the size of the incident.
Environmentally sensitive areas (officially designated or otherwise)	Pressure may be applied to give priority to a recovery strategy which favours the environment and protection of wildlife. Restricting access may be sufficient to meet these needs.)
Politically sensitive issues	At all levels of government political sensitivities and political agendas may influence recovery priorities.

4.5.2 Ethical considerations

The key ethical considerations that should be taken into account when developing a recovery strategy are given below. The issues are explored more comprehensively in Oughton et al. (2003).

- Self help. Options that are carried out by the affected population such as grass cutting, digging and indoor cleaning, can increase personal understanding or control over the situation. Furthermore, through their involvement, the population reinforce their autonomy, liberty and dignity. Conversely, imposed management options such as relocation can infringe upon liberty or restrict normal behaviour.
- Animal welfare. Animal welfare is concerned with the amount of suffering the management option may inflict on animals such as zoo animals, pets or wild animals.
- Environmental risk from changes to the ecosystem. Management options that change or interfere with ecosystems may have uncertain or unpredictable consequences for the environment. Environmental risk raises a variety of ethical issues including consequences for future generations, sustainability, cross-boundary pollution, and balancing harms to the environment/animals against benefits to humans. The acceptability of the management option will be highly dependent on the ecological status of the area and the degree to which the management option diverges from usual practice (e.g. shallow ploughing may be a normal practice whilst deep ploughing may be not). In most cases, environmental legislation must be considered (e.g. Natural Environment and Rural Communities (NERC) Act 2006, National Parks and Access to the Countryside Act 1949).

4.6 Environmental impact

The impact on the environment of management options should be considered during the decision making process in order to make sure that the action is justified. There are both positive and negative environmental impacts from the implementation of management options.

4.6.1 Positive environmental impacts

The replacement or treatment of roads and paved surfaces may lead to an improvement in their condition (depending on its original state).

4.6.2 Negative environmental impacts

If a significant number of people are relocated temporarily, the area they are sent to will experience increases in traffic which may result in a negative environmental impact through for example an increase in noise and air pollution. Where populations are permanently relocated, the siting of new buildings and infrastructure could impact negatively on the aesthetics of the environment. Similarly, where workforce access is prohibited to a building, the building and surrounding land could fall into disrepair.

Management options for grass, soil and outdoor surfaces can lead to a number of negative environmental impacts. For example, they can result in a decrease in biodiversity, a loss of plants and shrubs, a risk of soil erosion, partial or full loss of soil fertility, landscape changes, and other adverse effects. In addition, chemicals used for a tie-down option can themselves contaminate soil. The acceptability of covering a grass or soil area with tarmac in order to shield the population from contamination is likely to have a negative impact on the aesthetics of the environment.

4.7 Economic cost

The implementation of management options incurs economic costs, both direct and indirect. Examples of direct and indirect costs are given in Table 4.9. The magnitude of these costs depends on many factors, including:

- period of time over which a management option is implemented
- scale of the event: costs are proportional to the area of land affected
- land use
- availability of equipment and consumables.

It is difficult to predict the economic cost of implementing management options because of the numerous factors that influence cost (Alvarez-Farizo et al., 2009).

Table 4.9 Economic costs of the implementation of management options

Direct costs
Labour. It includes the salaries of workers implementing the management options and overhead costs for organising the work and an allowance for additional staff that may be required.
Cost of protection measures such as dosemeters and medical follow-up.
Loss of production because of the closure of businesses and industries.
Consumables and specific equipment necessary for particular management options, including handling of waste (see the datasheets in Section 3).
Communication, support, transportation and the need to verify laboratory analyses or screening techniques for quality assurance purposes.
Indirect costs
Changes to outdoor areas can have an impact on soil structure, fertility and may raise the risk of soil erosion. If options such as deep ploughing are implemented in areas where the water table is high, groundwater may be contaminated.
Temporary or permanent restriction of access and a reduction or loss of tourism may have an impact on businesses (particularly small businesses). Impact may also be experienced on the whole region if tourists avoid areas near to the contaminated area for fear of contamination.
Restrictions on subsequent land use once management options have been implemented may mean that people cannot live or work in certain areas or return to a normal lifestyle. This may result in relocation costs or business closures.

4.8 Information and communication issues

Following radioactive contamination of the environment, information and communication issues will be of the utmost importance, regardless of the scale or extent of the release. The manner in which communication is tackled is likely to have a significant impact on the response of society to the event and on the overall success of the management strategy. When planning in advance of an incident (see Section 5), a communication framework could be set up. Such a framework would, in the event of an incident, ensure appropriate communication and provision of information to those affected. Should no planning be made for communication in advance, it may be extremely challenging to ensure that the process is accurate, appropriate and consistent in the event of an incident.

Some of the communication and information issues that should be considered when developing a management strategy are:

- During the pre-deposition and early phases of a radiological incident, there is generally a lack of information available. Therefore, at these stages, there is much reliance on predictions about the scale and impact of the contamination and expected consequences. The authorities are the main communicators of information in the early phase.
- As the situation develops, sources of information and routes for dissemination grow rapidly. The more sources for dissemination there are available, the greater the chance of contradictory information being released. The authorities would need to cope with this situation and be in a position to provide accurate information.

- Prior to and during implementation of management options in a contaminated inhabited area, a well focussed communication strategy and dialogue should function with and between affected populations and other stakeholders. Information should deal with what management options have been selected and why, how do they work, how they are applied and by whom, what the societal economic and environmental impact
- As the situation changes and develops, conflict or disagreements may develop between affected populations. The reason for such dissent could be differences in the distribution of costs and benefits in the community from implementing the management options. It is essential that every opportunity for dialogue and debate about appropriate management strategies is taken to pre-empt these situations as much as possible.

The development of a detailed communication strategy is not discussed further in this Handbook. For more information see Nisbet et al., 2009

4.9 References

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CONTENTS OF SECTION 5

5 PLANNING FOR RECOVERY IN ADVANCE OF AN INCIDENT

There is a broad diversity of climatic conditions, types of inhabited area, culture, infrastructure and regulatory frameworks across Europe. Planning for recovery in advance of an incident will require customisation of this generic handbook at national, regional or local level. An essential component of the customisation process is the involvement of all stakeholders to better identify and include national/regional/local specificities. Practical recommendations for engaging with stakeholders in the management of contaminated areas are given in Appendix D.

The purpose of this chapter is to support the planning process by identifying the key topics that would need to be addressed and information that is needed to support the development of recovery strategies. Although much depends on the nature of the emergency or incident (e.g. its magnitude and the extent of radioactive contamination), consideration of topics such as ‘requirements for information’ and ‘outline arrangements’ prior to the occurrence of an incident would benefit the speed of recovery response and may also ensure a more successful outcome. Table 5.1 provides a breakdown of topics covering data and information requirements that could usefully be gathered in advance of an incident. The development and sharing of localised databases on businesses, suppliers of raw materials, contractors, waste disposal facilities and other information need to be considered. Although some of these databases may already exist in some form, the point of contact may not be widely known. Furthermore, it is important that the information is kept up to date and is maintained. Responsibility for this task for each database would need to be assigned. Due to the wide ranging nature of the information presented in Table 5.1, it is not yet clear how it would be assembled. Priorities would need to be assigned to help ensure the best use of available resources. Organisations at the local level would need to develop their own approach for preparing for a radiological emergency, according to their responsibilities and involvement. Table 5.2 gives a list of factors, in addition to the information requirements listed in Table 5.1 that might need to be considered when developing outline arrangements for a recovery strategy in advance of an incident. The strategy should be focussed at the local level and as a co-ordinated activity between all relevant agencies and stakeholders. Dialogue between different stakeholders is important in order to gain a balanced view on various aspects of topics at the national, regional or local level. It enables a common language and a shared understanding of the challenges to be developed. Various approaches for co-developing regional Handbooks with stakeholders can be used, including scenario-based workshops, feedback sessions on the datasheets and Handbook and the establishment of subgroups for more detailed planning on specific topics (e.g. waste management).

Table 5.1 Data and information that could be usefully gathered in advance of an incident

Topic	Category	Data and information requirements
Population	General issues	Distribution and size. Groups, e.g. school children, religious groups, patients, prisoners, tourists. Movements, e.g. commuters, students, holidaymakers. Time that the population spend outdoors, e.g. farmers versus office workers.
	Relocation	Numbers of people. Availability of and provision of resources for accommodation / housing. Availability of transport, private car ownership. Transport infrastructure, e.g. roads, railways.
Type of buildings		Construction method. Configuration, e.g. multi-storey, terraced, semi-detached, detached. Location factors. Air exchange / ventilation.
Types of sub-area / land use		Industrial. Recreational. Public buildings. Residential. Food production. Critical facilities (factories, hospitals etc). Infrastructure (water treatment works, sewage treatment plants, roads, railways etc). Designated sites (special protection areas, nature reserves, areas of outstanding natural beauty, Ramsar sites).
Background dose-rates (to aid monitoring and communication with the public)		Determine what the typical background gamma dose rates in the area are
Management options	Technical feasibility	Will the development of specific skills and methods be required? Identification of necessary training
	Available resources to implement recovery strategy	Local and regional availability of equipment and materials required. Costs of resources: labour costs, cost of materials and equipment. Need to maintain any "call-on" equipment for response purposes, e.g. fire tenders. Are skilled workers required to operate equipment? How many skilled workers are available? Would they work in contaminated areas?
	Personnel to implement management options	List of available contractors and organisations that can be contacted for advice on techniques, equipment, staff protection etc.
	Impact of geography and weather on management options	Availability of meteorological information, including weather forecasts. Use of geographical information systems to provide information on soil types, topography etc.
	Impact of management options on	What is the likely scale of the economic impact from

Table 5.1 Data and information that could be usefully gathered in advance of an incident

Topic	Category	Data and information requirements
	economy and environment	implementing management options? What options may have a positive impact? What options may have a negative impact?
	Acceptability of 'do no recovery' option / return to 'normality'	Draw on experience from other emergencies / natural disasters to identify what factors drive the return to normality, including experience of using different types of equipment. Look at whether decontamination or other management options promote or hinder this?
	Acceptability of management options	This is likely to be influenced by the type of radiological emergency/incident, its size, how the response is handled, the cause of the emergency etc. Public and other stakeholder views on the acceptability of the types of management options available could be sought to reduce the number of options to be considered in the event of a radiological emergency.
Waste management	Solid wastes	Authorised limits for incinerators, landfill sites, composting facilities etc. Number, type and capacities of facilities. Quantities of domestic refuse produced weekly, including garden waste. Ways to segregate contaminated garden waste from household domestic refuse. Normal practices for disposal of waste arising from the treatment of refuse, e.g. sewage sludge, incinerator ash, composted material. Disposal options for contaminated commercial goods that are unsaleable (not necessarily because they are highly contaminated) Site of waste storage and disposal facilities. Transport to the waste facility Legislation on construction of waste facilities.
	Contaminated waste water from natural run-off	Understanding of drainage and sewage plant systems in local area. What happens to excess water that bypasses treatment, e.g. water following rain storms or floods? What level of staff intervention is there during the sewage treatment process?
Legislation	Options	Environmental legislation may preclude implementation of some management options in the contaminated area (e.g. restriction placed on removal of trees).
	Workers and public	Establish dose limits for all those involved in recovery Establish criteria for transportation of radioactive wastes
Training		Consider developing a training programme for the roles required to be performed, e.g. decision-makers, decontamination workers and civil protection personnel. Provision of information on the objectives of the management option to ensure that those implementing the option understand why it is being undertaken and how the objective can be achieved. Leaflets to provide instruction on how to implement options correctly and effectively for situations where major training exercises are not possible.
Contacts		Lists of contacts in organisations that have a role in

Table 5.1 Data and information that could be usefully gathered in advance of an incident

Topic	Category	Data and information requirements
		the event of a radiological emergency. Lists of contacts with local information. Lists of country / regional / local databases that provide useful background data and information on how to access them.
Communication	Members of the public	Arrangements for communications via local/national TV and radio, websites. Timeline. Plan for engaging local people in decisions that will affect them. Compensation rights, including international agreements on compensation for radiological emergencies. Pre-prepared information that can be circulated to affected businesses. Receipts and record keeping. Pre-prepared information for others who may suffer financial losses due to the incident.
	Provision of information to implementers of management options	Provision of information on the objectives of the management option to ensure that those implementing the option understand why it is being undertaken and how the objectives can be achieved. Leaflets to provide instruction on how to implement options correctly and effectively.

Table 5.2 Factors and actions that may need to be considered when developing an outline recovery strategy for inhabited areas in advance of an incident

Topic	Factors and actions to consider
Generic strategy	Ensure information requirements (see Table 5.1) are prioritised, put into action, achieved and maintained – it is important to have confidence that information is complete, reliable and up-to-date. Establish mechanisms for accessing information. Procedures to characterise the longer-term situation will most likely be initiated in the emergency response phase. Therefore, recovery response plans should be consistent with their emergency response counterparts in order to ensure an uninterrupted flow of information and response. Think about how the recovery response strategy will link to management options implemented in the emergency phase. Think about employing a phased approach in which some contaminated areas are dealt with promptly, whereas other are treated later. Think about the role of self-help. Consider what the impact of different weather conditions and the geography of the area will have on the strategy and choice of management options. Produce and maintain a risk register for things that could go wrong in the development of the strategy (e.g. non-compliance). Identify barriers and establish which ones that will make the biggest difference.
Recovery criteria	Identify appropriate criteria to be used to determine the need for and scale of recovery management options and to measure their success.
Roles and responsibilities	Make sure the roles and responsibilities of those agencies that would undertake tasks in the recovery phase are well known. Identify leading agencies and legal responsibilities. Establish how the roles and responsibilities change along the timeline. Consider for each management option how available resources will be co-ordinated and moved to the affected area, e.g. the use of army, civil protection. This should be done at the national level to ensure consistency. Explore the best role of the local government and local agencies.
Role of stakeholders	Identify existing stakeholder groups in the area e.g. parish councils, community groups, existing fora (hospitals, schools). Investigate whether these could/would be prepared to provide feedback on a recovery strategy for the area. Consider processes that could be used to establish bespoke stakeholder panels where no relevant groups exist. Establish steps for each process considered.
Management options	Identify practicable and acceptable recovery options for use at the local level based on information provided in the handbooks in advance. Try engaging with the stakeholders. Consider: • any constraints on use of options (from Table 6.1 and datasheets in Section 3) • impact of weather conditions, i.e. when will options not be practicable due to snow, frozen surfaces, thunderstorms etc. • which options might be applicable to the range of possible emergency/incident scenarios? How might they be implemented? How will waste be managed? Aspects for each management option that will require consideration in advance of a radiological emergency and those that will be of particular importance to be taken into account in the event of a radiological emergency. Trials of the management options, to obtain a better understanding of the effectiveness and feasibility.
Protection of workers	Agreement between regulatory bodies, radiological protection specialists and employers on which recovery management options are likely to require the use of respiratory protection equipment and/or protective clothing. This should take into account the nature and extent of contamination, the time since the radiological emergency started and whether people are still living in the area.
Criteria for a successful strategy	Identify appropriate criteria to be used to determine the need for and scale of recovery countermeasures and to measure their success.

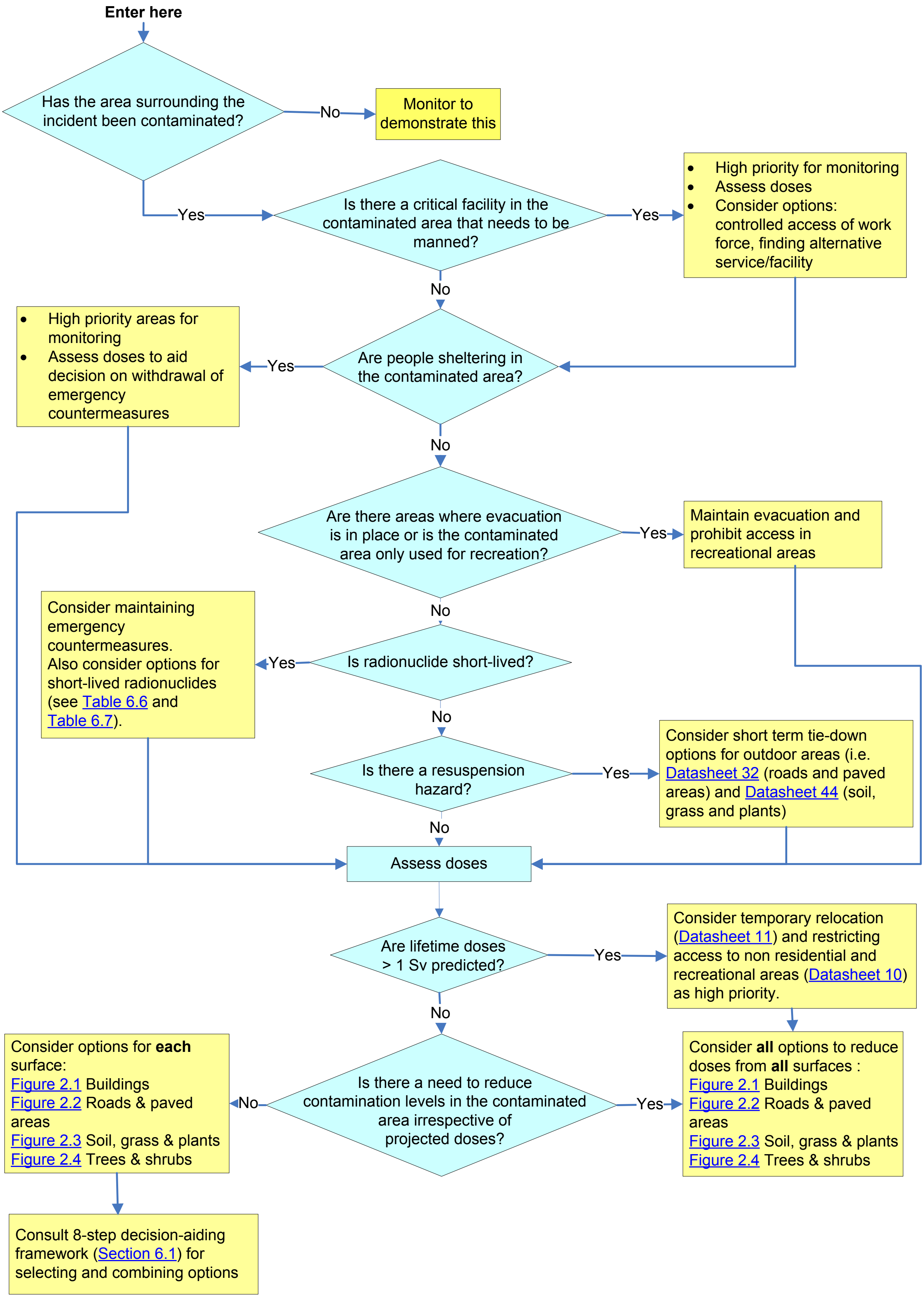
CONTENTS OF SECTION 6

6 CONSTRUCTING A MANAGEMENT STRATEGY

In order to develop a recovery strategy for an inhabited area, decision-makers will need to develop a framework for exploring the options. Throughout this process, they will require a significant amount of information to support decisions on timely and effective management options. The Handbook is a compilation of information to help users identify the important issues and evaluate the options. The overall decision framework (Figure 6.1) guides the user through the following steps: determining the nature of the incident and characterising the scale of the contamination (see also Section 1.9); estimating current and projected doses to people in contaminated inhabited areas (see also Section 1.12 and Appendix B); and considering appropriate recovery options (see also Section 2.1). The timescale, level of disruption and resource requirements associated with a given option will be strongly dependent on the size and nature of the area(s) contaminated. Therefore, it is important to recognise that flexibility must be retained in the choice of options, in order to accommodate the actual circumstances of the accident.

The Handbook provides information on 59 options (Section 3) to assist in management of buildings, roads and paved areas, soils, grass and plants, and trees and shrubs; only options relevant to the recovery phase are considered in this section. The selection of individual options depends on a wide range of criteria (temporal and spatial distribution of the contamination, effectiveness, economic cost, radiological and environmental impact, waste disposal, legislative issues and societal and ethical aspects for example), which are discussed in Section 4. For any one accident scenario only a subset of options will be applicable. However, as each accident will be different in terms of its radiological composition and impact on the foodchain it is not possible to devise a generic strategy. The following section provides a series of tables to guide decision makers to the most appropriate subset of management options through elimination of inappropriate options. Two worked examples are given in Section 7 on how to select and combine management options following contamination of an inhabited area with ^{137}Cs (example 1) and ^{239}Pu (example 2).

Figure 6.1 Decision tree for characterisation of the accident, requirement for monitoring and assessment of doses



6.1 Key steps in selecting and combining options

There are 8 key steps involved in selecting and combining options. These steps are summarised in Table 6.1 and described in more detail below.

Step 1: Identify the surfaces that are likely to have been contaminated (i.e. buildings, roads and paved areas, soils, grass and plants, shrubs and trees)

Step 2: Refer to selection tables for specific surfaces (Table 6.2 – Table 6.5). These selection tables provide a list of all of the applicable management options for the surface selected. The tables indicate whether the management options are suitable for implementation in the early or medium-late phases. The tables also provide an indication of whether the management options are likely to be practicable taking into account potential technical, logistical, economic or social constraints. The constraints are listed in more details for each option in a subsequent look-up table and in the individual datasheets in Section 3. The colour-coding classification used in the selection tables is intended to be a guide and would certainly require customization at local or regional level by relevant stakeholders.

Step 3: Refer to look-up Table 6.6 and Table 6.7 showing applicability of management options for each radionuclide being considered. This allows various options listed in the selection tables (Tables 6.2 – 6.5) to be eliminated if they are not suitable, based on the radiological hazard and half-life of the radionuclide(s).

Step 4: Refer to look-up Table 6.8 showing checklist of key constraints for each management option. These are constraints that would make implementation of an option very difficult if not impossible.

Step 5: Refer to look-up Table 6.9 – Table 6.14 showing the effectiveness of each management option in removing contamination from a surface or shielding people from contamination or reducing resuspension doses. This information may enable some of the least effective options to be eliminated, although management options are sometimes chosen for reasons other than radiological protection.

Step 6: Refer to look-up Table 6.15 showing which management options generate waste, including the type and quantities of waste produced. This information will not necessarily eliminate options but serves to warn the decision makers that selection of a particular option may have implications for waste disposal that requires further assessment.

Step 7: Refer to individual datasheets (Section 3) for all options remaining in the selection table and note the relevant constraints. It is likely that on a site specific basis, several more options will be eliminated from the selection tree as a result of additional constraints.

Step 8: Based on Steps 1-7, select and combine options for managing each phase of the accident and returning the area to normality.

By following Steps 1-8 it should be possible to devise a strategy, based on a combination of management options, which could be implemented following a release of radioactivity. These steps should be based on a participative approach with the stakeholders.

Table 6.1 Generic steps involved in selecting and combining options

Step	Action
1	Identify surfaces that are likely to be/have been contaminated
2	Refer to selection tables for specific surfaces (Table 6.2 – Table 6.5). These selection tables provide a list of all of the applicable management options for the surface selected
3	Refer to look-up tables Table 6.6 and Table 6.7 showing applicability of management options for each radionuclide being considered
4	Refer to look-up table (Table 6.8) showing a checklist of key constraints for each management option
5	Refer to look-up table (Table 6.9 – Table 6.14) showing effectiveness of options
6	Refer to look-up table (Table 6.15) showing type and amount of waste produced from implementation of management options
7	Refer to individual datasheets (Section 3) for all options remaining in the selection table and note the relevant constraints
8	Based on the outputs from Steps 1-7, select and combine options that should be considered as part of the recovery strategy

6.2 Selection tables

Selection tables are presented for the following surfaces:

- buildings (Table 6.2)
- roads and paved areas (Table 6.3)
- soils, grass and plants (Table 6.4)
- trees and shrubs (Table 6.5)

These selection tables provide:

- a list of all of the applicable management options for the surface selected.
- an indication of whether the management options are suitable for implementation in the first few days and weeks (classified here as the early phase) or months and years (classified here as or medium – long-term phase) after the incident.
- an indication of whether the management options are likely to be practicable based on knowledge of potential technical, logistical, economic or social constraints. The colour-coding distinguishes between: options that would usually be justified or recommended having few if any constraints; options that would also be recommended but would require further analysis to overcome potential constraints; options that would have to undergo a full analysis and consultation with stakeholders before implementation because of serious economic or social constraints and options that would only be justified in specific circumstances following full analysis and consultation due to major technical or logistical constraints. The classification used in the selection tables is intended to be a guide and requires Customization at local or regional level by the relevant stakeholders. The numbers in brackets in Tables 6.2 – 6.5 refer to the datasheet number.

Go to greyscale table

Table 6.2 Selection table of management options for buildings

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months – years)
Restrict access		
Permanent relocation from residential areas (8)	🟫	🟫
Prohibit public access to non-residential areas (9)	🟨	🟫
Restrict workforce access (time or personnel) to non-residential areas (10)	🟨	🟫
Temporary relocation from residential areas (11)	🟨	🟫
External surfaces		
Demolish buildings (12)	🟫	🟫
Firehosing (13)	🟩	🟥
High pressure hosing (14)	🟥	🟥
Mechanical abrasion of wooden walls (15)	🟨	🟥
Peelable coatings (49)	🟨	🟥
Roof brushing (16)	🟨	🟨
Roof cleaning with pressurised hot water (17)	🟨	🟨
Roof replacement (18)	🟫	🟫
Sandblasting (19)	🟥	🟥
Snow removal (50)	🟨	🟥
Tie down (fixing contamination to the surface) (20)	🟨	🟥
Treatment of walls with ammonium nitrate (21)	🟨	🟥
Indoor surfaces and objects		
Other cleaning methods (scrubbing, shampoo, steam cleaning) (23)	🟩	🟥
Removal of furniture, soft furnishings and other objects (24)	🟨	🟨
Surface removal (25)	🟨	🟨
Vacuum cleaning (26)	🟩	🟩
Washing (27)	🟩	🟥
Public buildings (e.g. railway stations)		
Aggressive cleaning of indoor contaminated surfaces (22)	🟨	🟨
Precious objects and personal items		
Storage, shielding, covering, gentle cleaning of precious objects (28)	🟩	🟫
Specialised surfaces in industrial buildings		
Application of detachable polymer paste on metal surfaces (53)	🟩	🟥
Chemical cleaning of metal surfaces (54)	🟨	🟥
Chemical cleaning of plastic and coated surfaces (55)	🟨	🟥
Cleaning of contaminated (industrial) ventilation systems (56)	🟨	🟨
Electrochemical cleaning of metal surfaces (57)	🟨	🟥
Filter removal (58)	🟩	🟩
Ultrasound treatment with chemical decontamination (59)	🟨	🟥

Key:

🟩	Recommended with few constraints
🟨	Recommended but requires further evaluation to overcome some constraints
🟫	Economic or social constraints exist, requiring full analysis and consultation period.
🟥	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to greyscale table

Table 6.3 Selection table of management options for roads and paved areas

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Permanent relocation from residential areas (8)	🟫	🟫
Prohibit public access to non-residential areas (9)	🟨	🟫
Restrict workforce access (time or personnel) to non-residential areas (10)	🟨	🟫
Temporary relocation from residential areas (11)	🟨	🟫
Removal and shielding options		
Firehosing (29)	🟩	🟥
High pressure hosing (30)	🟨	🟨
Snow removal (50)	🟨	🟥
Surface removal and replacement (31)	🟥	🟨
Tie down (fixing contamination to the surface) – bitumen (permanent) (32)	🟨	🟫
Tie down (fixing contamination to the surface) – sand (temporary) (32)	🟩	🟥
Tie down (fixing contamination to the surface) – water (temporary) (32)	🟩	🟥
Turning paving slabs (33)	🟨	🟨
Vacuum sweeping (34)	🟩	🟥

Key:

🟩	Recommended with few constraints
🟨	Recommended but requires further evaluation to overcome some constraints
🟫	Economic or social constraints exist, requiring full analysis and consultation period
🟥	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to greyscale table

Table 6.4 Selection table of management options for soils, grass and plants

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Permanent relocation from residential areas (8)	🟫	🟫
Prohibit public access to non-residential areas (9)	🟨	🟫
Restrict workforce access (time or personnel) to non-residential areas (10)	🟨	🟫
Temporary relocation from residential areas (11)	🟨	🟫
All open spaces		
Cover grassed and soil surfaces (e.g. with asphalt) (35)	🟫	🟫
Cover with clean soil (36)	🟨	🟨
Grass cutting and removal (38)	🟩	🟥
Plant and shrub removal (40)	🟨	🟥
Snow removal (50)	🟨	🟥
Tie-down (fixing contamination to the surface) (44)	🟫	🟥
Topsoil and turf removal (manual) (45)	🟥	🟫
Topsoil and turf removal (mechanical) (46)	🟥	🟫
Turf harvesting (48)	🟨	🟨
Small open spaces (e.g. gardens)		
Manual digging (39)	🟨	🟨
Rotovating (mechanical digging) (42)	🟨	🟨
Triple digging (47)	🟥	🟥
Large open spaces (e.g. parks, countryside)		
Deep ploughing (37)	🟨	🟨
Ploughing (41)	🟩	🟩
Skim and burial ploughing (43)	🟥	🟨

Key:

🟩	Recommended with few constraints
🟨	Recommended but requires further evaluation to overcome some constraints
🟫	Economic or social constraints exist, requiring full analysis and consultation period.
🟥	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to greyscale table

Table 6.5 Selection table of management options for trees and shrubs

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Permanent relocation from residential areas (8)	🟫	🟫
Prohibit public access to non-residential areas (9)	🟨	🟫
Restrict workforce access (time or personnel) to non-residential areas (10)	🟨	🟫
Temporary relocation from residential areas (11)	🟨	🟫
Removal options		
Collection of leaves (51)	🟩	🟥
Tree and shrub pruning/ removal (52)	🟥	🟥

Key:

🟩	Recommended with few constraints
🟨	Recommended but requires further evaluation to overcome some constraints
🟫	Economic or social constraints exist, requiring full analysis and consultation period
🟥	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

6.3 Applicability of management options for situations involving different radionuclides

Most of the practical information that is available on management options relates to radioactive isotopes of caesium following the Chernobyl accident in 1986 and from other experimental work undertaken for radionuclides of potential significance following accidents at nuclear facilities, for example, strontium and plutonium. For many of the other radionuclides considered in the Handbook there are few data to indicate whether a particular management option is effective or not. Nevertheless these radionuclides have certain characteristics in terms of their physical half-life, chemical properties and types of hazard posed to indicate whether an option should be considered.

In Table 6.6 and Table 6.7 an option is considered to be applicable if:

- there is direct evidence that it would be effective for a radionuclide (*known applicability*)
- the mechanism of action is such that it would be highly likely to be effective for a radionuclide (*probable applicability*)

The category of not applicable is attributed to an option if:

- there is direct evidence that it would not be effective for a radionuclide
- the chemical behaviour of the radionuclide is such that the option would not be expected to have any effect
- the hazard posed by the radionuclide would not be reduced by the management option (e.g. tie-down options for high energy gamma emitters)
- the physical half-life of the radionuclide is sufficiently short compared to the implementation time of the option to preclude its use (e.g. demolishing buildings would be unwarranted to address high levels of ^{131}I, which has a half-life of 8.04 days).

Table 6.6 Applicability of management options for radionuclides (Part 1)

Management options	Radionuclide										
	^{60}Co	^{75}Se	^{89}Sr	^{90}Sr/^{90}Y	^{95}Zr	^{99}Mo/ ^{99m}Tc	^{103}Ru	^{106}Ru	^{132}Te	^{131}I	^{134}Cs
Radionuclide half-life	5.27 y	119.8 d	50.5 d	29.12 y	63.98 d	66h/6.02h	39.28 d	368.2 d	78.2h	8.04d	2.06y
Restrict access											
Permanent relocation from residential areas (8)	✓	a	a	✓	a	a	a	✓	a	a	✓
Prohibit public access to non-residential areas (9)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Restrict workforce access (time or personnel) to non-residential areas (10)	b	✓	✓	b	✓	✓	✓	✓	✓	✓	b
Temporary relocation from residential areas (11)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Buildings											
Aggressive cleaning of indoor contaminated surfaces (22)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Demolish buildings (12)	✓	a	a	✓	a	a	a	a	a	a	a
Firehosing (13)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
High pressure hosing (14)	✓	✓	a	✓	a	a	✓	✓	✓	✓	✓
Mechanical abrasion of wooden walls (15)	✓	✓	a	✓	a	a	✓	✓	✓	✓	✓
Other cleaning methods (scrubbing, shampoo, steam cleaning) (23)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Peelable coatings (49)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Removal of furniture, soft furnishings and other objects (24)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Roof brushing (16)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Roof cleaning with pressurised hot water (17)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Roof replacement (18)	✓	a	a	✓	a	a	a	✓	a	a	✓
Sandblasting (19)	✓	✓	✓	✓	✓	a	a	✓	a	a	✓
Snow removal (50)	✓	✓	✓	✓	✓	a	✓	✓	a	✓	✓
Storage, shielding, covering and gentle cleaning of precious objects (28)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Surface removal (25)	✓	✓	a, f	✓	✓	a	✓	✓	a	a	✓
Tie-down (fixing contamination to the surface) (20)	c	c	✓	✓	c	c	c	c	c	c	c
Treatment of walls with ammonium nitrate (21)	e	e	e	e	e	e	e	e	e	e	✓
Vacuum cleaning (26)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Washing (27)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Roads and paved areas											
Firehosing (29)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 6.6 Applicability of management options for radionuclides (Part 1)

Management options	Radionuclide										
	^{60}Co	^{75}Se	^{89}Sr	^{90}Sr/^{90}Y	^{95}Zr	^{99}Mo/ ^{99m}Tc	^{103}Ru	^{106}Ru	^{132}Te	^{131}I	^{134}Cs
Radionuclide half-life	5.27 y	119.8 d	50.5 d	29.12 y	63.98 d	66h/6.02h	39.28 d	368.2 d	78.2h	8.04d	2.06y
High pressure hosing (30)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Peelable coatings (49)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Snow removal (50)	✓	✓	✓	✓	✓	a	✓	✓	a	✓	✓
Surface removal and replacement (31)	✓	a	a	✓	a	a	a	✓	a	a	✓
Tie down (fixing contamination of the surface) (32)	c	c	✓	✓	c	c	c	c	c	c	c
Turning paving slabs (33)	✓	✓	✓	✓	✓	a	a	✓	a	a	✓
Vacuum sweeping (34)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Soil, grass and plants											
Cover grassed and soils surfaces (e.g. with asphalt) (35)	f	a	a	✓	a	a	a	✓	a	a	✓
Cover with clean soil (36)	f	✓	✓	✓	✓	a	✓	✓	a	a	✓
Deep ploughing (37)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Grass cutting and removal (38)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Manual digging (39)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Plant and shrub removal (40)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Ploughing (41)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Rotovating (mechanical digging) (42)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Skim and burial ploughing (43)	✓	✓	a	✓	✓	a	a	✓	a	a	✓
Snow removal (50)	✓	✓	✓	✓	✓	a	✓	✓	a	✓	✓
Tie-down (fixing contamination to the surface) (44)	c	c	✓	✓	c	c	c	c	c	c	c
Topsoil and turf removal (manual) (45)	✓	✓	a	✓	a	a	a	✓	a	a	✓
Topsoil and turf removal (mechanical) (46)	✓	✓	a	✓	a	a	a	✓	a	a	✓
Triple digging (47)	✓	a	a	✓	a	a	a	✓	a	a	✓
Turf harvesting (48)	✓	✓	a	✓	a	a	a	✓	a	a	✓
Trees and shrubs											
Collection of leaves (51)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Tree & shrub pruning/removal (52)	✓	✓	a	✓	a	a	a	✓	a	a	✓
Specialised surfaces											

Table 6.6 Applicability of management options for radionuclides (Part 1)

Management options	Radionuclide										
	^{60}Co	^{75}Se	^{89}Sr	^{90}Sr/^{90}Y	^{95}Zr	^{99}Mo/ ^{99m}Tc	^{103}Ru	^{106}Ru	^{132}Te	^{131}I	^{134}Cs
Radionuclide half-life	5.27 y	119.8 d	50.5 d	29.12 y	63.98 d	66h/6.02h	39.28 d	368.2 d	78.2h	8.04d	2.06y
Application of detachable polymer paste on metal surfaces (53)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Chemical cleaning of metal surfaces (54)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Chemical cleaning of plastic and coated surfaces (55)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Cleaning of contaminated (industrial) ventilation systems (56)	✓	✓	f	f	✓	a	✓	✓	a	a	✓
Electrochemical cleaning of metal surfaces (57)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Filter removal (58)	✓	✓	✓	✓	✓	a	✓	✓	a	✓	✓
Ultrasound treatment with chemical decontamination (59)	✓	✓	✓	✓	✓	a	✓	✓	a	✓	✓

Key:

Half-life: h = hours, d = days, y = years

✓: Selected as target radionuclide (i.e. known or probable applicability, see Section 6.3)

a Comparatively short physical half-life of radionuclide relative to timescale of implementation of the management option

b Comparatively long physical half-life of radionuclide relative to timescale that the management option can be left in place

c This management option reduces doses from inhalation of resuspended material which is not an important pathway for this radionuclide (beta/gamma hazard)

d This management option reduces doses from external irradiation which is not an important pathway for this radionuclide (alpha hazard)

e This management option is specific for radiocaesium

f This management option will not have any noticeable effect in removing contamination or reducing doses for this radionuclide.

Table 6.7 Applicability of management options for radionuclides (Part 2)

Management options	Radionuclide										
	^{136}Cs	^{137}Cs	^{140}Ba	^{144}Ce	^{169}Yb	^{192}Ir	^{226}Ra	^{235}U	^{238}Pu	^{239}Pu	^{241}Am
Radionuclide half-life	13.1d	30y	12.7d	284.3d	32d	74d	1.6 10^3y	7.04 10^8y	87.7y	2.4 10^4y	432.2y
Restrict access											
Permanent relocation from residential areas (8)	a	✓	a	a	a	a	✓	✓	✓	✓	✓
Prohibit public access to non-residential areas (9)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Restrict workforce access (time or personnel) to non-residential areas (10)	✓	b	✓	✓	✓	✓	b	b	b	b	b
Temporary relocation from residential areas (11)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Buildings											
Aggressive cleaning of indoor contaminated surfaces (22)	a	✓	a	✓	a	✓	✓	✓	✓	✓	✓
Demolish buildings (12)	a	✓	a	✓	a	a	✓	✓	✓	✓	✓
Firehosing (13)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
High pressure hosing (14)	a	✓	a	✓	a	✓	✓	✓	✓	✓	✓
Mechanical abrasion of wooden walls (15)	a	✓	a	✓	a	✓	✓	✓	✓	✓	✓
Other cleaning methods (scrubbing, shampoo, steam cleaning) (23)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Peelable coatings (49)	a	✓	a	✓	a	✓	✓	✓	✓	✓	✓
Removal of furniture, soft furnishings and other objects (24)	a	✓	a	✓	a	✓	✓	✓	✓	✓	✓
Roof brushing (16)	a	✓	a	✓	✓	✓	✓	✓	✓	✓	✓
Roof cleaning with pressurised hot water (17)	a	✓	a	✓	a	✓	✓	✓	✓	✓	✓
Roof replacement (18)	a	✓	a	✓	a	a	✓	✓	✓	✓	✓
Sandblasting (19)	a	✓	a	✓	a	✓	✓	✓	✓	✓	✓
Snow removal (50)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Storage, shielding, covering, gentle cleaning of precious objects (28)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Surface removal (25)	a	✓	a	✓	a	✓	✓	✓	✓	✓	✓
Tie-down (fixing contamination to the surface) (20)	c	c	c	c	c	c	✓	✓	✓	✓	✓
Treatment of walls with ammonium nitrate (21)	✓	✓	e	e	e	e	e	e	e	e	e
Vacuum cleaning (26)											
Washing (27)											
Roads and paved areas											
Firehosing (29)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 6.7 Applicability of management options for radionuclides (Part 2)

Management options	Radionuclide										
	^{136}Cs	^{137}Cs	^{140}Ba	^{144}Ce	^{169}Yb	^{192}Ir	^{226}Ra	^{235}U	^{238}Pu	^{239}Pu	^{241}Am
Radionuclide half-life	13.1d	30y	12.7d	284.3d	32d	74d	1.6 10^3y	7.04 10^8y	87.7y	2.4 10^4y	432.2y
High pressure hosing (30)	a	✓	a	✓	a	✓	✓	✓	✓	✓	✓
Peelable coatings (49)	a	✓	a	✓	a	✓	✓	✓	✓	✓	✓
Snow removal (50)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Surface removal and replacement (31)	a	✓	a	✓	a	a	✓	✓	✓	✓	✓
Tie down (fixing contamination of the surface) (32)	c	c	c	c	c	c	✓	✓	✓	✓	✓
Turning paving slabs (33)	a	✓	a	✓	a	✓	✓	✓	✓	✓	✓
Vacuum sweeping (34)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Soil, grass and plants											
Cover grassed and soils surfaces (e.g. with asphalt) (35)	a, f	✓	a, f	✓	a	a	f	✓	✓	✓	✓
Cover with clean soil (36)	a, f	✓	a, f	✓	a	a	f	✓	✓	✓	✓
Deep ploughing (37)	a	✓	a	✓	✓	✓	✓	✓	✓	✓	✓
Grass cutting and removal (38)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Manual digging (39)	a	✓	a	✓	✓	✓	✓	✓	✓	✓	✓
Plant and shrub removal (40)	a	✓	a	✓	✓	✓	✓	✓	✓	✓	✓
Ploughing (41)	a	✓	a	✓	✓	✓	✓	✓	✓	✓	✓
Rotovating (mechanical digging) (42)	a	✓	a	✓	✓	✓	✓	✓	✓	✓	✓
Skim and burial ploughing (43)	a	✓	a	✓	a	✓	✓	✓	✓	✓	✓
Snow removal (50)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tie-down (fixing contamination to the surface) (44)	c	c	c	c	c	c	✓	✓	✓	✓	✓
Topsoil and turf removal (manual) (45)	a	✓	a	✓	a	a	✓	✓	✓	✓	✓
Topsoil and turf removal (mechanical) (46)	a	✓	a	✓	a	a	✓	✓	✓	✓	✓
Triple digging (47)	a	✓	a	✓	a	a	✓	✓	✓	✓	✓
Turf harvesting (48)	a	✓	a	✓	a	a	✓	✓	✓	✓	✓
Trees and shrubs											
Collection of leaves (51)	a	✓	a	✓	✓	✓	✓	✓	✓	✓	✓
Tree & shrub pruning/removal (52)	a	✓	a	✓	a	a	✓	✓	✓	✓	✓
Specialised surfaces											

Table 6.7 Applicability of management options for radionuclides (Part 2)

Management options	Radionuclide										
	^{136}Cs	^{137}Cs	^{140}Ba	^{144}Ce	^{169}Yb	^{192}Ir	^{226}Ra	^{235}U	^{238}Pu	^{239}Pu	^{241}Am
Radionuclide half-life	13.1d	30y	12.7d	284.3d	32d	74d	1.6 10^{3}y	7.04 10^{8}y	87.7y	2.4 10^{4}y	432.2y
Application of detachable polymer paste on metal surfaces (53)	a	✓	a	✓	a	✓	d	d	d	d	d
Chemical cleaning of metal surfaces (54)	a	✓	a	✓	a	✓	d	d	d	d	d
Chemical cleaning of plastic and coated surfaces (55)	a	✓	a	✓	a	✓	d	d	d	d	d
Cleaning of contaminated (industrial) ventilation systems (56)	a	✓	a	✓	a	✓	d	d	d	d	d
Electrochemical cleaning of metal surfaces (57)	a	✓	a	✓	a	✓	d	d	d	d	d
Filter removal (58)	✓	✓	a	✓	✓	✓	d	d	d	d	d
Ultrasound treatment with chemical decontamination (59)	✓	✓	✓	✓	✓	✓	d	d	d	d	d

Key:

Half-life: h = hours, d = days, y = years

✓: Selected as target radionuclide (i.e. known or probable applicability, see Section 6.3)

a Comparatively short physical half-life of radionuclide relative to timescale of implementation of the management option

b Comparatively long physical half-life of radionuclide relative to timescale that the management option can be left in place

c This management option reduces doses from inhalation of resuspended material which is not an important pathway for this radionuclide (beta/gamma hazard)

d This management option reduces doses from external irradiation which is not an important pathway for this radionuclide (alpha hazard)

e This management option is specific for radiocaesium

f This management option will not have any noticeable effect in removing contamination or reducing doses for this radionuclide.

6.4 Checklist of key constraints for each management option

Management options invariably have constraints associated with their implementation. A detailed description of these constraints is provided in the datasheets for each option (Section 3). To assist in eliminating unsuitable options some of the key constraints for each option have been summarised in Table 6.8. These tables can be used in conjunction with the datasheets or beforehand to reduce the subset of options that require more in-depth analysis. The numbers in brackets in Table 6.7 refers to the datasheet number.

Table 6.8 Checklist of key constraints to consider when selecting management options

Restrict access	
Permanent relocation from residential areas (8)	Availability of new housing
	Infrastructure to support relocated populations
Prohibit public access to non-residential areas (9)	Enforcement (total prohibition needed)
Restrict workforce access (time or personnel) to non-residential areas (10)	Availability of system to monitor and control doses
	Can only be maintained for a limited time
Temporary relocation from residential areas (11)	Alternative accommodation
	Not applicable for timescales > 1 year
	Infrastructure to support relocated populations
Buildings	
Aggressive cleaning of indoor contaminated surfaces (22)	Surfaces must be waterproof and resist water at high pressure
	Damage (flooding)
	Use in listed and historic buildings
Demolish buildings (12)	Historic and listed buildings
	Also need to implement options on surrounding land to be effective
	Very slow work rate[c]
Firehosing (13)	Severe cold weather
	Damage (flooding)
	Needs to be implemented quickly and before rain[d]
	Use on historic and listed buildings
	Walls and roofs must be resistant to water at high pressure
High pressure hosing (14)	Severe cold weather
	Damage (flooding)
	Use on historic and listed buildings
	Walls and roofs must be resistant to water at high pressure
Mechanical abrasion of wooden walls (15)	Use on listed and historic buildings
	Damage to surfaces
	Very slow work rate[c]
Other cleaning methods (scrubbing, shampoo, steam cleaning) (23)	Use in listed and historic buildings and precious objects
	Type of surface / robustness of surface to intensive cleaning
Peelable coatings (49)	Severe cold weather, wet weather
	Use on small areas only

Table 6.8 Checklist of key constraints to consider when selecting management options

	Materials not widely available
	Use on listed and historic buildings
Removal of furniture, soft furnishings and other objects (24)	Use in listed and historic buildings and precious objects
	Small scale only
Roof brushing (16)	Severe cold weather
	Use on historic and listed buildings (potential damage)
	Availability of equipment
	Very slow work rate[c]
Roof cleaning with pressurised hot water (17)	Severe cold weather
	Roof construction must resist water at high pressure
	Availability of equipment
	Very slow work rate[c]
	Use on listed and historic buildings (potential damage)
Roof replacement (18)	Use on listed and historic buildings
	Large amount of waste[a]
	Access
	Building materials, eg asbestos
	Slow work rate[c]
Sandblasting (19)	Use on listed and historic buildings
	Large team size[b]
	Damage to surfaces
	Surfaces need to be resistant to high water pressure
	Severe cold weather
Snow removal (50)	Access to roofs
Storage, shielding, covering, gentle cleaning of precious objects (28)	Small scale only
	Potential damage or personal possessions or significant objects
Surface removal (25)	Use on listed and historic buildings
	Small scale only
Tie-down (fixing contamination to the surface) (20)	Severe cold weather
	May need repeating to remain integrity of covering
	Use on listed and historic buildings (damage)
	Complicates further options involving removal of surface
	Wet weather
Treatment of walls with ammonium nitrate (21)	Severe cold weather
	Walls must be water resistant
	Very slow work rate[c]
	Needs to be implemented quickly and before rain[d]
	Use on listed and historic buildings (damage)
Vacuum cleaning (26)	Use in listed and historic buildings and precious furniture/ objects (damage)
Washing (27)	Use in listed and historic buildings and on precious objects (damage)

Table 6.8 Checklist of key constraints to consider when selecting management options

Roads and paved areas	
Firehosing (29)	Severe cold or wet weather
	Needs to be implemented quickl[y]
	Needs drains
High pressure hosing (30)	Severe cold weather
	Needs drains
Peelable coatings (49)	Use on small areas only
	Use in conservation areas / historic sites
	Materials not widely available
Snow removal (50)	Implement before first thaw
	Access
	Severe cold leading to ice compaction
Surface removal and replacement (31)	Uneven surface/road camber
	Large amounts of waste[a]
	Tie-down needed to suppress dust
	Large team size[b]
Tie-down (fixing contamination to the surface (32)	Tie-down with water not possible in cold weather
	May need repeating to remain integrity of covering
	Complicates further options involving removal of surface
	Tie-down with bitumen not practicable if very cold
Turning paving slabs (33)	Use on small areas only
	Tie-down needed to suppress dust
	Very slow work rate[c]
Vacuum sweeping (34)	Severe cold weather
	Access around buildings
	Needs to be implemented quickly and before rain[d]
Soil, grass and plants	
Cover grassed and soils surfaces (e.g. with asphalt) (35)	Severe cold weather (frost or snow)
	Complicates further options involving removal of soil
	Acceptability in gardens likely to be low
	Use on small areas only
	Use in conservation areas / historic sites
	Steep slope
Cover with clean soil (36)	Use on listed or historic sites or in conservation area
	Very large quantities of soils required
	Complicates further options involving removal of soil
	Loss of plants and shrubs
Deep ploughing (37)	Severe cold weather (frost or snow)
	Soil texture (not appropriate for sandy soils)
	Loss of soil fertility
	Implement before normal ploughing
	Further ploughing reduces effectiveness
	Complicates further options involving removal of soil
	Large areas only

Table 6.8 Checklist of key constraints to consider when selecting management options

	Tie-down needed to suppress dust
	Soil depth > 0.5m is required
Grass cutting and removal (38)	Severe cold weather (frost or snow)
	Heavy rain after deposition
	Needs to be implemented quickly and before rain[d]
	PPE required as dust suppression not possible
	Steep slopes
	Need grass mowers with collection boxes
Manual digging (39)	Severe cold weather (frost or snow)
	Use in conservation areas / historic sites
	Area must not have been tilled since deposition
	Area must mot be re-dug
	Complicates further options involving removal of soil
	Use on small areas only
	Very slow work rate[c]
Plant and shrub removal (40)	Severe cold weather (frost or snow)
	Needs to be implemented quickly and before rain[d]
	Dependent on time of year. Only if leaves on plants and shrubs
	PPE required as dust suppression not possible
	Use in conservation areas / historic sites
Ploughing (41)	Severe cold weather (frost or snow)
	Use in conservation areas / historic sites
	Tie-down needed to suppress dust
	Use on large areas only
	Soil depth > 0.3m is required
	Complicates further options involving removal of soil
	Further ploughing reduces effectiveness
Rotovating (mechanical digging) (42)	Severe cold weather (frost or snow)
	Use on small areas only
	Area must mot be re-dug
	Area must not have been tilled since deposition
	Use in conservation areas / historic sites
	Complicates further options involving removal of soil
Skim and burial ploughing (43)	Severe cold weather (frost or snow)
	Soil texture (not appropriate for sandy soils)
	Implement before normal ploughing
	Loss of plants and shrubs
	Skilled personnel needed
	Availability of equipment
	Use on large areas only
	Complicates further options involving removal of soil
	Soil depth > 0.5m is required

Table 6.8 Checklist of key constraints to consider when selecting management options

Snow removal (50)	Obstacles e.g. trees
	Implement before first thaw
	Slope
Tie-down (fixing contamination to the surface) (44)	Severe cold weather (frost or snow)
	Resuspension only suppressed while integrity of covering remains intact
	Chemical contamination of soil
	Implement before rain
Topsoil and turf removal (manual) (45)	Severe cold weather (frost or snow)
	Soil texture (not appropriate for stony soils)
	Use in conservation areas / historic sites
	Large amounts of waste[a]
	Use on small areas only
	Very slow work rate[c]
	Large team required if reseeding or returfing[b]
Topsoil and turf removal (mechanical) (46)	Severe cold weather (frost or snow)
	Soil texture (not appropriate for stony soils)
	Use in conservation areas / historic sites
	Tie-down needed to suppress dust
	Large amounts of waste[a]
	Large team required if reseeding or returfing[b]
Triple digging (47)	Severe cold weather (frost or snow)
	Area must not have been tilled since deposition
	Area must not be re-dug
	Use in conservation areas / historic sites
	Use on small areas only
	Complicates further options involving removal of soil
	Very slow work rate[c]
Turf harvesting (48)	Availability of equipment
	Rocky areas / uneven ground
	Large amounts of waste[a]
	Tie-down needed to suppress dust
	Severe cold weather (frost or snow)
Trees and shrubs	
Collection of leaves (51)	Extreme slopes
	Dependent on time of year. Must be carried out soon after leaf fall
	Likely to need to repeat for coniferous trees
Tree & shrub pruning/removal (52)	Must be carried out before leaf fall
	Severe cold weather (frost or snow)
	PPE needed as can't protect against dust
Specialised surfaces	
Application of detachable polymer paste on metal surfaces (53)	Very slow work rate[c]
	Small areas only

Table 6.8 Checklist of key constraints to consider when selecting management options

Chemical cleaning of metal surfaces (54)	Chemical incompatibility between decontaminant and chemicals on metal surface
	Very slow work rate[c]
Chemical cleaning of plastic and coated surfaces (55)	Chemical incompatibility between decontaminant and chemicals on metal surface
	Very slow work rate[c]
Cleaning of contaminated (industrial) ventilation systems (56)	Very slow work rate[c]
Electrochemical cleaning of metal surfaces (57)	Very slow work rate[c]
	Very small sale only
Filter removal (58)	Skilled personnel required
	PPE required
Ultrasound treatment with chemical decontamination (59)	Not recommended for concrete or plastic.
	Very slow work rate[c]
	Small areas only

a Large amounts of waste is defined as > 30 kg m^{-2} of solid waste

b A large team is defined as > a team of 5 people is required to implement management option

c A very slow work rate is defined as < 10 m^2 per team hour

d Needs to be undertaken quickly is defined as < 7 days following deposition.

6.5 Effectiveness of management options

The primary aim of management options in inhabited areas is to reduce doses from external irradiation from deposited radionuclides and inhalation from resuspension of contaminated material.

Management options are directed at shielding people from contamination, fixing the contamination so that it cannot be resuspended and inhaled, or removing the contamination so that exposure is reduced, providing waste is disposed of properly. Effectiveness of management options, in terms of the reduction in contamination people are exposed to, is expressed in different ways according to the purpose for which it is implemented:

- The effectiveness of shielding is expressed as the percentage reduction in external dose rate from a surface following implementation of the option
- The effectiveness of fixing is expressed as the percentage reduction in inhalation dose rate from a surface following implementation of the option
- The effectiveness of removal is expressed as a Decontamination Factor (DF), which is the ratio of the amount of contamination initially present on a specific surface to that following implementation of the option

The overall impact of the management option on the doses received by an individual living in an inhabited area depends on the contributions from contamination on each surface and the time people spend close to these surfaces (see Section 1.12)

Table 6.9 – Table 6.14 summarise the effectiveness of each management option considered in the Handbook, according to its mode of action. The dose reductions

presented in the tables are illustrative and should only be used to scope the level of reduction that is likely to be achieved. The dose reductions achieved will be dependent on the specific situation, habits of the population and the effectiveness of the management option. Dose reductions are given following initial deposition under dry and wet conditions in the first year following deposition. Further details can be found in the datasheets. Doses are for a typical inhabited area comprising a variety of housing types and surrounding land. In this hypothetical inhabited area, all surfaces are present and the amounts of these surfaces have been estimated. The reductions in external dose given in the datasheets assume that a person spends all of their time in this environment, of which 90% is spent indoors. The reductions in dose are estimated taking into account the contribution of the dose over time from all the surfaces in the environment and any reduction in the contamination levels on a surface due to cleaning removal or mixing. ^{137}Cs is illustrative of a long-lived beta/gamma emitter, where external gamma doses dominate and resuspension doses are not significant. ^{239}Pu is illustrative of a long-lived alpha emitter where resuspension doses dominate and external doses are insignificant.

Table 6.9 Effectiveness of management options in reducing doses when access is restricted

Management option	Mode of action	Principal exposure pathway	Effectiveness		Comments
			Surface	Overall	
Permanent relocation from residential areas (8)	Shielding	External gamma External beta Resuspension	See comments	Up to 100% reduction in dose	It does not reduce contamination levels in the environment
Prohibit public access to non-residential areas (9)	Shielding	External gamma External beta Resuspension	Up to 100% reduction in dose (all pathways) from areas where access is prohibited	Not estimated	Particularly useful for short-lived radionuclides. Effectiveness depends on individuals complying. It does not reduce contamination levels in the environment
Restrict workforce access (time or personnel) to non-residential areas (10)	Shielding	External gamma External beta Resuspension	See comments	Not estimated	Effective in controlling doses to an essential workforce as long as people comply and controls are enforced. This option does not reduce contamination levels in the environment. Particularly useful for short-lived radionuclides.
Temporary relocation from residential areas (11)	Shielding	External gamma External beta Resuspension	See comments	Up to 100% reduction in dose (all pathways) while individual is away from affected area.	Particularly useful for short-lived radionuclides. It does not reduce contamination levels in the environment

Table 6.10 Effectiveness of management options in reducing doses for buildings

Management option	Mode of action	Principal exposure pathway	Effectiveness		Comments
			Surface	Overall	
Aggressive cleaning of indoor contaminated surfaces (22)	Removal	External gamma External beta Resuspension	DF of up to 10 if implemented within a few weeks of deposition.	Reductions in doses are likely to be similar to those for washing indoor surfaces (assuming a similar occupancy indoors).	DF quoted for high pressure hosing and sandblasting of concrete, stone and brick surfaces (floors and walls) and no previous cleaning has taken place. For smooth surfaces, such as tiles, linoleum, and glass, a higher DF could be expected. Repeated application is unlikely to provide any significant increase in DF.
Demolish buildings (12)	Removal	External gamma External beta	All contamination is removed if all debris is removed and contamination is not spread during demolition.	See comments	100% reduction in doses from buildings after demolition may enable resettlement of the area in the future.
Firehosing (13)	Removal	External gamma External beta	DF of 1.3 can be achieved if implemented within 1 week of deposition and before significant rain.	5-10% reduction in external gamma dose if dry deposition (<5% reduction if wet deposition)	Repeated application is unlikely to provide any significant increase in DF.
High pressure hosing (14)	Removal	External gamma External beta	DF of typically 1.5 - 5 can be achieved if implemented soon after deposition.	< 5% reduction in external and resuspension doses	A higher DF can be achieved following dry deposition rather than wet deposition. Repeated application is unlikely to provide any significant increase in DF.
Mechanical abrasion of wooden walls (15)	Removal	External gamma External beta	DF of typically 1.5 – 2.5 can be achieved if implemented soon after deposition	Reduction of 5% could be expected in external gamma dose following dry deposition (negligible reductions following wet deposition).	Repeated application is unlikely to provide any significant increase in DF.
Other cleaning methods (scrubbing, shampoo, steam cleaning) (23)	Removal	External gamma External beta	DF of up to 10 assuming that this option is implemented within a few weeks of deposition and no previous cleaning has taken place	Reductions in doses are likely to be similar to those for washing indoor surfaces.	The highest DFs can be expected from cleaning smooth surfaces (i.e. wood, tiles, linoleum, Marley tiles, glass and papered and painted walls). Lower DFs are likely for cleaning rough surfaces (i.e. concrete, stone and brick surfaces and for carpets, rugs, tapestries, upholstery, bedding and soft furnishings.

Table 6.10 Effectiveness of management options in reducing doses for buildings

Management option	Mode of action	Principal exposure pathway	Effectiveness		Comments
			Surface	Overall	
Peelable coatings (49)	Removal, fixing	External gamma External beta	DF of up to 5 if implemented within a few weeks. While the peelable coating is in place, resuspended activity in air will be reduced by almost 100 %.	5-10% reduction in external gamma dose if dry deposition (<5% reduction if wet deposition)	This option is likely to be most effective when used on smooth surfaces. Later application is likely to give a lower DF, particularly on porous building materials such as bricks and tiles.
Removal of furniture, soft furnishings and other objects (24)	Removal	External gamma External beta	If carried out carefully, virtually all the contamination on the surface may be removed.	Reductions in doses are likely to be similar or maybe slightly higher than those for washing indoor surfaces.	The process of removing objects may result in the spread of contamination onto other surfaces via dust which will reduce the overall effectiveness.
Roof brushing (16)	Removal	External gamma	DF of 2 - 7	Reductions of <5 % could be expected in external gamma dose following dry deposition (10 – 15% following wet deposition).	Repeated application is unlikely to provide any significant increase in DF.
Roof cleaning with pressurised hot water (17)	Removal	External gamma	DF of 2 - 7 could be achieved if implemented soon after deposition (DF of 2-4 after 10 years).	Reductions in external dose will be similar to those for roof brushing.	If a surface layer of moss/algae covers the roof at the time of deposition, almost all the contamination may be removable.
Roof replacement (18)	Removal	External gamma	All contamination from roof removed	Reductions in external gamma dose of up to 10% could be expected.	May need to consider if any contamination has penetrated into underlying construction materials
Sandblasting (19)	Removal	External gamma	DF of 4 – 10 could be achieved if implemented soon after deposition (will decrease with time).	Reductions of 5 - 10 % could be expected in external gamma dose following dry deposition (negligible reductions following wet deposition).	Repeated application is unlikely to provide any significant increase in DF.
Snow removal (50)	Removal	External gamma	DF of 10 - 30 if implemented prior to the snow melting and as long as snow is removed to a depth to include the contamination	Reductions of 10-15 % could be expected in external gamma dose based on the likely importance of roofs in contributing to doses.	Resuspension from a snow-covered surface will be generally low.

Table 6.10 Effectiveness of management options in reducing doses for buildings

Management option	Mode of action	Principal exposure pathway	Effectiveness		Comments
			Surface	Overall	
Storage, shielding, covering, gentle cleaning of precious objects (28)	Shielding, removal	External gamma External beta Resuspension	100 – 200 mm of concrete or brick and 10mm of lead will typically give a reduction in gamma dose rate of a factor of 2. 1 – 5 mm of glass will prevent external beta dose rates.	Very dependent on situation and likely to be very small for most individuals.	Effectiveness depends on the radionuclides present and the thickness of the shielding material. A gamma emitter will need a greater thickness of shielding material than a low energy beta emitter.
Surface removal (25)	Removal	External gamma External beta Resuspension	If carried out carefully, virtually all the contamination on the surface may be removed.	Reductions in doses are likely to be similar or maybe slightly higher than those for washing indoor surfaces.	The process of removing paper, paint or plaster may result in the spread of contamination onto other surfaces via dust, reducing the effectiveness.
Tie-down (fixing contamination to the surface) (20)	Fixing, shielding (low energy beta emitters)	Resuspension	Up to 100% reduction in resuspension dose from surface while integrity of covering is maintained.	Not estimated.	This option may be effective at reducing external beta dose rates above the surface (for low energy beta emissions) while the tie-down remains intact, but is not effective at reducing external gamma dose rates.
Treatment of walls with ammonium nitrate (21)	Removal	External gamma from radioacesium	DF of 1.5 – 2 could be achieved if implemented soon after deposition (DF of 1.5 could be expected up to a few years)	Reductions in external dose are unlikely to be more than a few percent following dry deposition (negligible following wet deposition).	Repeated application is unlikely to provide any significant increase in DF.
Vacuum cleaning (26)	Removal	External gamma External beta Resuspension	DF of 5 – 10 achievable assuming that this option is implemented within a few weeks of deposition and no previous cleaning has taken place.	Reductions of <5 % could be expected in external gamma dose. Reductions of 35 – 40% in resuspension dose could be expected following dry deposition (<5 % following wet deposition).	Repeated application is unlikely to provide any significant increase in DF.
Washing (27)	Removal	External gamma External beta Resuspension	DF of 1.5 – 3 achievable assuming that this option is implemented within a few weeks of deposition and no previous cleaning has taken place.	Reductions of <5 % could be expected in external gamma dose. Reductions of 35 – 40% in resuspension dose could be expected following dry deposition (<5 % following wet deposition).	Repeated application is unlikely to provide any significant increase in DF.

Table 6.11 Effectiveness of management options in reducing doses for roads and paved areas

Management option	Mode of action	Principal exposure pathway	Effectiveness		Comments
			Surface	Overall	
Firehosing (29)	Removal	External gamma External beta Resuspension	DF of 2 - 4 if implemented within one week of deposition and there has been no significant rain.	5-10% reduction in external gamma and resuspension dose if wet deposition (<5% reduction if dry deposition).	Repeated application is unlikely to provide any significant increase in DF.
High pressure hosing (30)	Removal	External gamma External beta	DF of 3 - 7 if implemented soon after deposition.	10-15% reduction in external gamma if wet deposition (<5% reduction if dry deposition).	Repeated application is unlikely to provide any significant increase in DF.
Peelable coatings (49)	Removal, fixing	External gamma External beta Resuspension	DF of up to 5 if implemented within a few weeks. While the peelable coating is in place, resuspended activity in air will be reduced by ~ 100 %.	10-15% reduction in external gamma dose if dry deposition (<5% reduction if wet deposition) Similar reductions in resuspension dose	This option is likely to be most effective when used on smooth surfaces.
Snow removal (50)	Removal	External gamma External beta	DF of 10 - 30 if implemented prior to snow melt and as long as snow is removed to a depth to include contamination	Up to 80% reduction in external gamma dose if all outdoor surfaces (including soil and grass areas) are cleared from snow.	
Surface removal and replacement (31)	Removal	External gamma External beta Resuspension	DF of 5 -10	15-20% reduction in external gamma dose if wet deposition (<5% if dry deposition). 5-10% reduction in resuspension dose if wet deposition (negligible reduction if dry deposition).	Repeated application is unlikely to provide any significant increase in DF.
Tie down (fixing contamination of the surface) (32)	Fixing, shielding (low energy beta emitters)	Resuspension External beta	Up to 100% reduction in resuspension dose from surface while integrity of covering is maintained. Reductions in external beta dose rates above the surface: 90% for sand, 70 % for bitumen and 45 % for water.	Not estimated.	This option is not effective at reducing external gamma dose rates. Sand (2 mm) would be the most effective at reducing beta dose rates, typical thicknesses of bitumen (1 mm) and water (1 mm) will give less protection.
Turning paving slabs (33)	Shielding	External gamma External beta	External gamma dose rates above the surface will be	Likely to be lower than those for surface removal and replacement.	This option will be very effective at reducing external beta dose rates,

Table 6.11 Effectiveness of management options in reducing doses for roads and paved areas

Management option	Mode of action	Principal exposure pathway	Effectiveness		Comments
			Surface	Overall	
		Resuspension	reduced by 75-85% for medium to high gamma-emitting radionucldies. Up to 100% reduction for external beta doses and resuspension dose from the surface		which will be negligible after implementation. Reductions in external gamma dose received by an individual living in the area will be very dependent on the amount of the outdoor paved area that is covered with paving slabs. Likely to only be used for small areas or locations that are particularly sensitive, e.g. schools.
Vacuum sweeping (34)	Removal	External gamma External beta Resuspension	DF of 2 – 3 if implemented within one week of deposition and before rain.	5-10% reduction in external gamma and resuspension dose if wet deposition (<5% if dry deposition)	Repeated application is unlikely to provide any significant increase in DF

Table 6.12 Effectiveness of management options in reducing doses for soil, grass and plants

Management option	Mode of action	Principal exposure pathway	Effectiveness		Comments
			Surface	Overall	
Cover grassed and soils surfaces (e.g. with asphalt) (35)	Shielding	External gamma External beta Resuspension	100% for external beta dose rates above the surface. 30-80% reductions in external gamma dose rate above the surface depending on radionuclide Resuspended concentrations in air above the surface will be reduced by 100%	Up to 40% reduction in external gamma dose if all soil and grass areas are covered with asphalt.	While the asphalt remains undisturbed, the external gamma dose rate above the surface will be reduced by a factor which is dependent on the energy of the gamma rays emitted and the depth of the asphalt layer used. Reductions in external gamma dose received by an individual living in the area will be very dependent on the amount of the soil and grass area that is covered with asphalt. Likely to only be used for small areas or locations that are particularly sensitive, e.g. schools.
Cover with clean soil (36)	Shielding, fixing	External gamma External beta Resuspension	100% reduction in external beta dose rates above the surface 30-80% reductions in external gamma dose rate above the surface depending on radionuclide. Up to 100% reduction in resuspension dose from the surface	Up to 40% reduction in external gamma dose if all soil and grass areas are covered with clean soil.	While the clean layer remains undisturbed, the external gamma dose rate above the surface will also be reduced by a factor which is dependent on the energy of the gamma rays emitted and the depth of the clean soil layer used. Reductions in external gamma dose received by an individual living in the area will be very dependent on the amount of the soil and grass area that is covered with clean soil. Likely to only be used for small areas or locations that are particularly sensitive, e.g. schools.
Deep ploughing (37)	Shielding	External gamma External beta Resuspension	External gamma dose rates above the surface will be reduced by 80 - 90% for medium to high energy gamma emitters. Resuspended concentrations in air above the surface will be reduced by 90 – 95%	15-20% reduction in external gamma dose. <5% reduction in resuspension dose if dry deposition (5-10% if wet deposition).	Beta dose rate reduction is likely to be significantly higher than the values given for gamma dose rates if the technique is implemented effectively. By effectively burying most of the contamination, resuspended activity in air above the surface will be reduced by a factor significantly larger than the external gamma dose rate reduction
Grass cutting and removal (38)	Removal	External gamma External beta Resuspension	DF of 2 - 10 if implemented within one week of deposition and before significant rain occurs.	20-25% reduction in external gamma dose if dry deposition (10-15% if dry deposition). 5-10% reduction in resuspension dose.	Effectiveness is significantly reduced after rain has occurred or if grass has been already cut post deposition.

Table 6.12 Effectiveness of management options in reducing doses for soil, grass and plants

Management option	Mode of action	Principal exposure pathway	Effectiveness		Comments
			Surface	Overall	
Manual digging (39)	Shielding	External gamma External beta Resuspension	External gamma and beta dose rates above the surface are likely to be reduced by up to 80% in the short-medium term. Resuspended concentrations in air above the surface will be reduced by 90 – 95%	20-25% reduction in external gamma dose if dry deposition (25-30% if wet deposition). 5-10% reduction in resuspension dose if dry deposition (10-15% if wet deposition).	Effectiveness depends on the success of mixing within the soil. Dose rate reductions are likely to be higher than those for mechanical digging since rotovation does not bury contamination under a clean soil layer but mixes (dilutes) it homogeneously over the treated depth.
Plant and shrub removal (40)	Removal	External gamma External beta Resuspension	DF of 2 - 10 if implemented within one week of deposition and before significant rain occurs.	10-15% reduction in external gamma dose. 10-15% reduction in resuspension dose following wet deposition (<5% following dry deposition).	Effectiveness is significantly reduced after rain has occurred. Only effective before foliage dies back in autumn/winter.
Ploughing (41)	Shielding	External gamma External beta Resuspension	External gamma dose rates above the surface will be reduced by 50 – 80% for medium to high energy gamma emitters Resuspended concentrations in air above the surface will be reduced by 90 – 95%	10-15% reduction in external gamma dose if dry deposition (15-20% reduction if wet deposition). <5% reduction in resuspension dose if dry deposition (10 -15% if wet deposition).	The reductions in external gamma dose rate will depend on the radionuclides involved, the ploughing depth and the soil contamination profile with depth at the time of implementation. Beta dose rate reduction is likely to be significantly higher than the values given for gamma dose rates if the technique is implemented effectively.
Rotovating (mechanical digging) (42)	Shielding	External gamma External beta Resuspension	External gamma and beta dose rates above the surface are likely to be reduced by 50 - 65% in the short-medium term. Resuspended concentrations in air above the surface will be reduced by 90 – 95%	10-15% reduction in external gamma dose if dry deposition (15-20% reduction if wet deposition). 5-10% reduction in resuspension dose if dry deposition (20 – 25% if wet deposition).	Effectiveness depends on the success of mixing within the soil. Dose rate reductions are likely to be less than those for manual digging since rotovation does not bury contamination under a clean soil layer but mixes (dilutes) it homogeneously over the treated depth.

Table 6.12 Effectiveness of management options in reducing doses for soil, grass and plants

Management option	Mode of action	Principal exposure pathway	Effectiveness		Comments
			Surface	Overall	
Skim and burial ploughing (43)	Shielding	External gamma External beta Resuspension	External gamma and beta dose rates above the surface are likely to be reduced by 80 – 90% Up to 100% for external beta doses Up to 100% reduction in resuspension dose	15-20% reduction in external gamma dose. <5% reduction in resuspension dose if dry deposition (5-10% if wet deposition).	External gamma dose rates above the surface will be reduced by a factor of 5 - 10 for medium to high energy gamma emitters, such as caesium. The reductions in dose rate will depend on the radionuclides involved, i.e. their gamma energies. The reduction will also depend on the ploughing depth and the soil contamination profile with depth at the time of implementation and the success of the implementation.
Snow removal (50)	Removal	External gamma External beta	DF of 10 – 30 if implemented prior to the snow melting and as long as snow is removed to a depth to include the contamination	Up to 80% reduction in external gamma dose if all outdoor surfaces (including soil and grass areas) are cleared from snow.	
Tie-down (fixing contamination to the surface) (44)	Fixing, shielding (low energy beta emitters)	Resuspension External beta	Up to 100% reduction in resuspension dose from surface while integrity of covering is maintained. Small reductions in external beta dose rates above the surface could be expected.	Not estimated.	Applying water will aid the bonding of activity to soil particles and can wash contamination below the surface, both of which will reduce resuspension in the longer term.
Topsoil and turf removal (manual) (45) Topsoil and turf removal (mechanical) (46)	Removal	External gamma External beta Resuspension	DF of 10 – 30 can be achieved if implemented within a few years of deposition.	35-40% reduction in external gamma dose if dry deposition (40-45% if wet deposition). 5-10% reduction in resuspension dose if dry deposition (15-20% if wet deposition).	The removal depth needs to be chosen to ensure maximum removal of contamination in order to achieve maximum effectiveness. If a standard removal depth is used, the effectiveness will reduce in time after this as contamination migrates to deeper soil depths.

Table 6.12 Effectiveness of management options in reducing doses for soil, grass and plants

Management option	Mode of action	Principal exposure pathway	Effectiveness		Comments
			Surface	Overall	
Triple digging (47)	Shielding	External gamma External beta Resuspension	External gamma dose rates above the surface are likely to be reduced by up to 90% and beta dose rates reduced by 100% assuming the top layer of soil is buried. Resuspended concentrations in air above the surface will be reduced to zero.	Reductions in overall dose likely to be a little higher than those for manual digging.	Effectiveness depends on the radionuclide, i.e. the energy of the gamma rays and the technique being applied correctly so that the top layer of soil is completely buried.
Turf harvesting (48)	Removal	External gamma External beta Resuspension	DF of 3-10 if implemented within the first few years after deposition.	35-40% reduction in external gamma dose if dry deposition (40-45% if wet deposition). 5-10% reduction in resuspension dose if dry deposition (15-20% if wet deposition).	Effectiveness reduces after first year as contamination migrates to deeper soil levels.

Table 6.13 Effectiveness of management options in reducing doses for trees and shrubs

Management option	Mode of action	Principal exposure pathway	Effectiveness		Comments
			Surface	Overall	
Collection of leaves (51)	Removal	External gamma External beta Resuspension	DF of up to 50	See comments	Most contamination on trees and shrubs is associated with the leaves. So, the decontamination factor (DF) is likely to be similar to that for tree removal if leaves are on the trees at the time of deposition and all the leaves are collected. This option will be less effective for coniferous trees, even if collection is repeated several times. Reductions in external gamma dose could be expected to be similar to those given for tree removal if the trees were predominantly deciduous.
Tree & shrub pruning/removal (52)	Removal	External gamma External beta Resuspension	DF of up to 50	**Dry deposition:** reductions of approx 20 % in external gamma dose rate could be expected shortly after removal of contaminated trees/shrubs. **Wet deposition:** reductions in dose rate will be negligible	The reduction in contamination is proportional to the fraction of the tree/shrub removed. If a whole tree is felled and all the leaves are collected, a very high DF (up to 50) could be achieved.

Table 6.14 Effectiveness of management options for specialist surfaces

Management option	Mode of Action	Principal exposure pathway	Effectiveness
			Surface
Application of detachable polymer paste on metal surfaces (53)	Removal	All radionuclides	DF of 4 - 30
Chemical cleaning of metal surfaces (54)	Removal	External gamma External beta	DF of 2 – 30 for soft techniques DF of > 30 (up to 100) for hard techniques
Chemical cleaning of plastic and coated surfaces (55)	Removal	External gamma External beta	DF of 10 - 100
Cleaning of contaminated (industrial) ventilation systems (56)	Removal	External gamma External beta	DF of 5-30 for high pressure hosing DF of 5-10 for vacuum brushing
Electrochemical cleaning of metal surfaces (57)	Removal	External gamma External beta	DF of up to 100
Filter removal (58)	Removal	External gamma External beta	DF of up to 100
Ultrasound treatment with chemical decontamination (59)	Removal	External gamma External beta	DF of 10-100 on metal surfaces

6.6 Quantities and types of waste produced from implementation of management options

One important criterion to consider when assessing the practicability of a management option is whether it generates waste. Shielding options have an advantage in that they do not usually produce any waste because the contamination is left in situ. Removal options will generate contaminated waste material (liquid and/or solid) which will require management (e.g. storage or disposal). Table 6.15 presents information on the quantities and types of waste produced for each management option considered in the Handbook. All values are for illustrative purposes to enable the impact of the implementation of the various options to be scoped and a comparison across options to be made. No collection of waste and segregation is assumed unless stated. If waste materials can be segregated into contaminated and exempt waste, quantities of contaminated waste will be much smaller. For example, water can be collected, filtered and re-used.

Table 6.15 Quantities and types of waste produced by the management options

Management option	Waste arising kg m^{-2} unless otherwise stated	Waste material
Restrict access		
Permanent relocation from residential areas (8)	None	
Prohibit public access to non-residential areas (9)	None	
Restrict workforce access (time or personnel) to non-residential areas (10)	None	
Temporary relocation from residential areas (11)	None	
Buildings		
Aggressive cleaning of indoor contaminated surfaces (22)	Variable	Various
Demolish buildings (12)	7 10^{1}	Rubble
Firehosing (13)	1 10^{-1} – 2 10^{-1}	Dust
	5 10^{1} litres m^{-2}	Water
High pressure hosing (14)	2 10^{-1} – 4 10^{-1}	Dust
	2 10^{1} litres m^{-2}	Water
Mechanical abrasion of wooden walls (15)	1 10^{-1}	Dust
Other cleaning methods (scrubbing, shampoo, steam cleaning) (23)	1.3	Water, detergent, dust and filters
Peelable coatings (49)	1	Rubber-like material
Removal of furniture, soft furnishings and other objects (24)	2 10^{1} – 3 10^{1}	Flooring
	5 10^{1}	Fixtures
Roof brushing (16)	2 10^{-1} – 6 10^{-1}	Dust and moss
	1.5 10^{1} litres m^{-2}	Water
Roof cleaning with pressurised hot water (17)	2 10^{-1}	Dust and moss
	3 10^{1} litres m^{-2}	Water
Roof replacement (18)	2 10^{1} – 5 10^{1}	Roofing material
Sandblasting (19)	3	Dust and sand
	5 10^{1} litres m^{-2}	Water
Snow removal (50)	5 10^{-1} (5 cm depth removed)	Snow
Storage, shielding, covering, gentle cleaning of precious objects (28)	Small quantities	Water from cleaning
Surface removal (25)	4 10^{-1}	Carpet
	1 10^{-1}	Plaster
	1	Paint, wallpaper
	4	Linoleum
	7	Wood
Tie-down (fixing contamination to the surface) (20)	4 10^{-1}	Paint
Treatment of walls with ammonium nitrate (21)	6 litres m^{-2}	Liquid
Vacuum cleaning (26)	5 10^{-3}	Dust and filters
Washing (27)	1 10^{-3} – 2 10^{-3}	Dust and water
Roads and paved areas		
Firehosing (29)	1 10^{-1} – 2 10^{-1}	Dust
	< 5 10^{1} litres m^{-2}	Water
High pressure hosing (30)	2 10^{-1} – 4 10^{-1}	Dust

Table 6.15 Quantities and types of waste produced by the management options

Management option	Waste arising kg m^{-2} unless otherwise stated	Waste material
	2 10^{1} litres m^{-2}	Water
Surface removal and replacement (31)	1.5 10^{1} (per cm depth removed)	Asphalt
	3 10^{1} (per cm depth removed)	Paving slabs, concrete
Tie-down (fixing contamination to the surface) (32)	3 10^{-1} litres m^{-2}	Water and dust
	1 – 2	Sand and dust
	No waste	Bitumen (permanent)
Turning paving slabs (33)	None	
Vacuum sweeping (34)	1 10^{-1} – 2 10^{-1}	Dust and sludge
Soil, grass and plants		
Cover grassed and soils surfaces (e.g. with asphalt) (35)	None	
Cover with clean soil (36)	None	
Deep ploughing (37)	None	
Grass cutting and removal (38)	< 1 10^{-3}. Amount depends on height and density of grass	Grass
Manual digging (39)	None	
Peelable coatings (49)	1	Rubber-like material;
Plant and shrub removal (40)	2 (fresh mass)	Vegetation and shrubby material
Ploughing (41)	None	
Rotovating (mechanical digging) (42)	None	
Skim and burial ploughing (43)	None	
Snow removal (50)	5 10^{-1} (if 5cm snow removed)	Snow
Tie-down (fixing contamination to the surface) (44)	None	
Topsoil and turf removal (manual) (45)	6 10^{1} – 7 10^{1} (5 cm depth removed)	Soil and turf
Topsoil and turf removal (mechanical) (46)	6 10^{1} – 7 10^{1} (5 cm depth removed)	Soil and turf
Triple digging (47)	None	
Turf harvesting (48)	2 10^{1} – 3 10^{1} (2 – 2.5 cm depth removed)	Soil and turf
Trees and shrubs		
Collection of leaves (51)	5 10^{-1}	Leaves, pine needles and pinecones
Tree & shrub pruning/removal (52)	1 10^{1} (tree felling)	Wood and vegetation
Special surfaces		
Application of detachable polymer paste on metal surfaces (53)	2 10^{-1} - 2	Solid
Chemical cleaning of metal surfaces (54)	5 – 3 10^{1} litres m^{-2}	Liquid
Chemical cleaning of plastic and coated surfaces (55)	5 – 3 10^{1} litres m^{-2}	Liquid
Cleaning of contaminated (industrial) ventilation systems (56)	5 10^{-2} – 1 10^{-1}	Solid waste (dry from filters, wet sludge from pressure washing)
Electrochemical cleaning of metal surfaces (57)	5 – 1.5 10^{1} litres m^{-2}	Liquid
Filter removal (58)	x	Filter
Ultrasound treatment with chemical decontamination (59)	3 – 2.5 10^{1} litres m^{-2}	Liquid

6.7 Comparing the remaining management options

Once options have been eliminated from the selection tables, if appropriate, the next step is to identify all the remaining options that could be considered for the type of surface affected. These options need to be evaluated on a site-specific basis using detailed information provided in the datasheets (Section 3). Software tools such as ERMIN (Jones et al, 2009) may help to evaluate some of the consequences of implementing management options. In terms, for example, of dose reductions, resources necessary, costs and amounts of waste generated, which may help to identify options that are not worth pursuing.

In order to aid with the selection of a strategy, a table could be designed to compare remaining management options. Table 6.16 gives an example of a template that could be used for such a purpose.

Table 6.16 Criteria which can be used to compare possible management options for a contaminated inhabited area.

Criteria (can be tailored as required)	Option 1	Option 2	Option 3
Effectiveness (approx amount of contamination removed)			
Approx dose reduction to population groups of concern			
Waste generation			
Resources			
Cost			
Doses to workers implementing options			
Other advantages			
Other disadvantages			
Time scale for implementation			
Justification for choice of option			
Legal implications			

6.8 References

Jones A, Charnock T, Singer L, Roed J, Andersson K, Thykier Nielsen S, Mikkelsen T, Astrup P, Kaiser J, Müller H, Pröhl G, Raskob W, Hoe S, Jacobsen LH, Schou-Jensen L, Gering F (2009). Description of the Modelling of Transfer and Dose Calculations within ERMIN. EURANOS(CAT2)-TN(05)-04

CONTENTS OF SECTION 7

7 WORKED EXAMPLES

The following worked examples have been developed to help users become familiar with the content of the Handbook and its structure. They are also useful for training purposes. It should be emphasised however that the scenarios used are only illustrative and have been included solely to support training in the use of the Handbook. The worked examples should not be used as proposed solutions to the contamination scenarios selected.

Two scenarios have been developed:

1. a major accident at a nuclear power plant involving the release of ^{137}Cs;
2. a small scale radiological emergency involving the dispersion of ^{239}Pu.

7.1 Example 1 – A major accident at a nuclear power plant involving the release of ^{137}Cs

Scenario

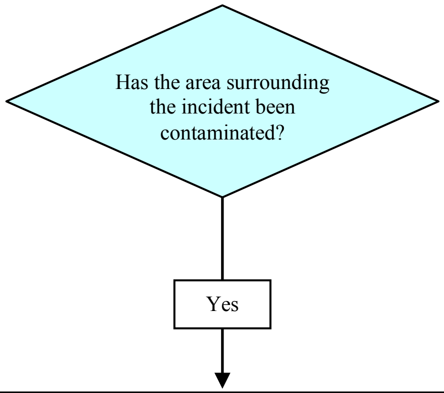
- A large nuclear reactor accident on 1st June at a power plant close to a city
- Atmospheric release of radioactive material
- Rain as the contaminated plume passes overhead, leading to wet deposition of contaminants

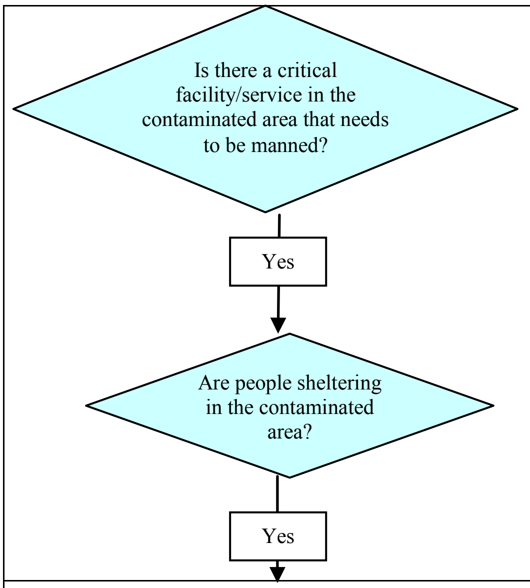
Current situation

- The release is over
- The contaminated plume has passed
- Contamination levels have not yet been determined
- The population has not been evacuated from the city and is still sheltering

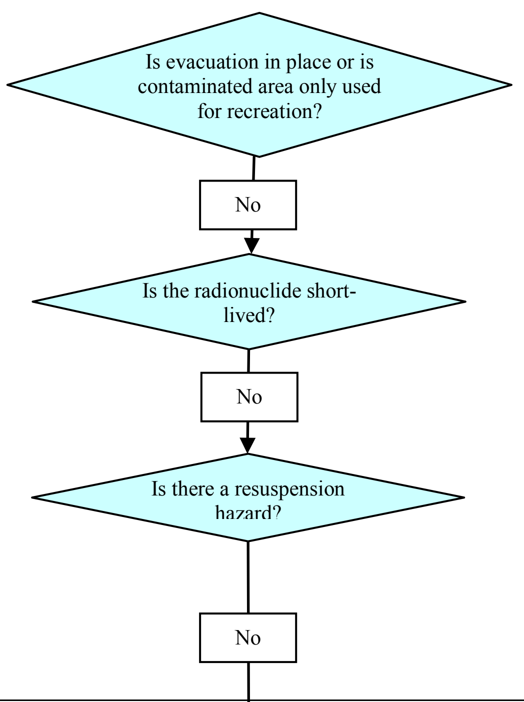
7.1.1 Decision framework for developing a recovery strategy

It is first necessary to consult the decision tree for developing a recovery strategy: characterisation of accident, monitoring and doses Figure 6.1.

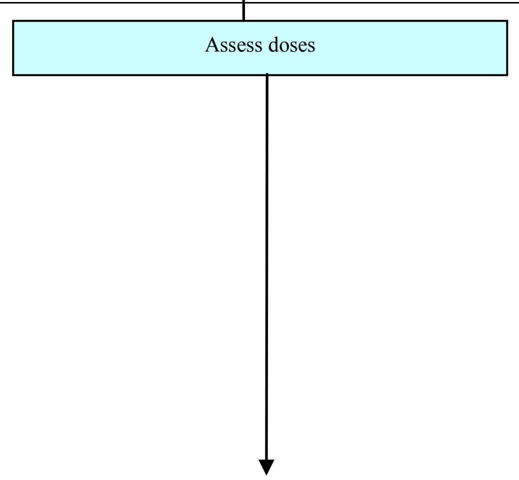
	• Scope the nature of contamination in the inhabited area. Refer to Section 1.9 for guidance. • Monitoring*:* grass and soil samples are taken to the laboratory. Analysis shows the contamination on the surface to be dominated by 1 MBq m^{-2} ^{137}Cs (Figure 7.1) • Consult Section 1.7 to find out what hazard ^{137}Cs presents. Table 1.1 shows that ^{137}Cs gives rise to a long-lived gamma hazard.



- Because the contaminated area is a city, there is a high chance of critical facilities and services (e.g. water supplies, power) being present which need to be manned, especially because the population has not been evacuated.
- Figure 6.1 shows that both the critical facilities and areas where people are sheltering are high priority areas for monitoring.
- Planning in advance should mean that a list of critical facilities is available (see Section 5 for guidance on planning in advance).
- People are sheltering.



- No evacuation has taken place and it is not a recreational area.
- ^{137}Cs gives rise to long-lived external gamma exposure. Management options need to be selected appropriate to this exposure pathway.
- Resuspended material can be inhaled. Table A3 indicates that ^{137}Cs may give rise to small resuspension doses. Using the dose conversion factors in Table B4, the integrated dose from this pathway over 10 years can be estimated to be about 8 10^{-12} Sv per Bq m^{-2}. With a contamination level of 1 MBq m^{-2}, this gives 0.008 mSv, which is very low in comparison with the external gamma dose.



Section 1.12 on estimating doses in inhabited areas refers the user to Appendix B for further information on calculating the doses. Appendix B2 provides the equation to calculate external gamma dose from sources in the outdoor environment.

- Ground deposition was measured as 1 MBq m^{-2}. The external dose outdoors from Table B2 over 50 years is 1.3 10^{-7} Sv per Bq m^{-2}. The fraction of time spent outdoors is about 10%. The location factor from Table B3 ranges from 0.03 to 0.62 depending on the shielding offered by a particular type of building.

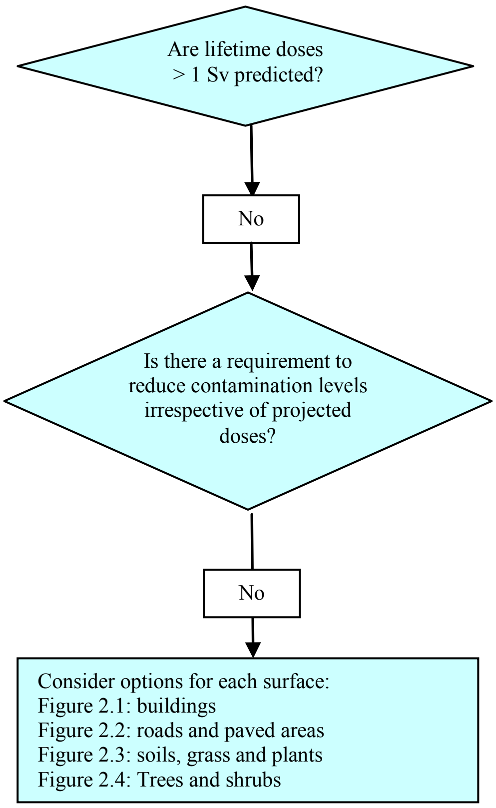
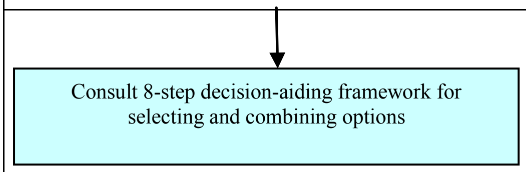
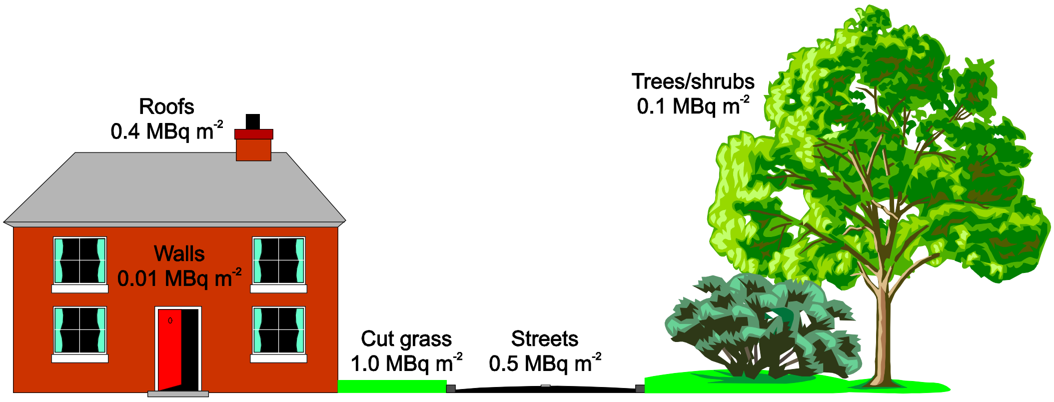
	• Using the formula in Appendix B, an external gamma dose to inhabitants is estimated to be between 17and 86 mSv over 50 years, depending on the location factor used. Similarly, the external gamma dose over 1 year can be estimated to be 2 – 8 mSv. • Other contributions to the dose are minor: Section 1.8.1 indicates that doses from indoor contamination would be low because the deposition was wet; Table A3 indicates that beta doses from ^{137}Cs would be small.
	• The doses estimated above are compared against the radiological protection criteria referred to in Section 1.11. The lifetime dose is less than 1 Sv and projected doses in the first year are less than 10 mSv. It is unlikely that highly disruptive management options would be justified. Nevertheless, some intervention to reduce radiation exposures would usually be justified at the levels of dose predicted. • People are sheltering in the city. Therefore it may not be practicable to carry out the more disruptive options or those that affect properties where people are living or those which produce dust. Consideration could be given to temporarily relocating people during the implementation of management options. • There is no pressure to remove the contamination from the whole area. However, the city contains locations that are particularly sensitive (e.g. schools). In such locations, there is likely to be pressure to undertake decontamination.
	The 8-step decision-aiding framework described in Section 6.1 and presented below in Table 7.1 should now be consulted. Select and combine management options for each contaminated surface.

Figure 7.1 Contamination levels of ^{137}Cs on the various types of surface in the city for the hypothetical scenario given in Example 1



7.1.2 Choosing management options

For the purposes of this example, only soil and grassed areas are considered further; these are principally assumed to be small city gardens. Justification for this choice is given in step 1 in Table 7.1. In reality, the decision making process would be much more complicated. Options would need to be assessed for all surfaces in the inhabited area. This would take into account, for example, resource implications, quantities of waste, constraints on implementation, effectiveness, cost and social impact.

The development of a recovery strategy for city gardens makes use of the decision framework described in Section 6. Before going through the generic steps involved in selecting and combining options it is important for users to appreciate that when using the Inhabited Areas Handbook to develop a recovery strategy they should establish a dialogue with national and local stakeholders; be familiar with the structure and content of the Handbook; develop knowledge of technical information underpinning a recovery strategy and an understanding of the factors influencing implementation of options and selection of a strategy (Section 4).

The development of a recovery strategy for city gardens areas using the accident scenario for ^{137}Cs is described in Table 7.1 below, based on the eight generic steps described in Section 6.1. The numbers in brackets in Tables 7.2 – 7.9 refer to the datasheet number.

Table 7.1 Steps involved in selecting and combining options for city gardens contaminated with ^{137}Cs

Step	Action
1	**Identify surfaces that are likely to be/have been contaminated**
	In determining priorities, it is important to take into account the relative importance of different surfaces in contributing to the doses received. From the scenario, earlier results from the analysis of the grass/soil samples revealed that there was 1 MBq m^{-2} of ^{137}Cs on grassed surfaces. Using Table B5, it is possible to estimate the likely levels of contamination on other surfaces in the area, as shown in Figure 7.1. This provides an indication of the surfaces that are likely to have received the most contamination. Figure 1.4 also gives an indication of the surfaces that are likely to contribute to external gamma doses, taking into account both the contamination on the different surfaces and the time people are likely to spend close to/on these surfaces. Using this information, contaminated soil/grass areas, roofs and streets would generally be expected to contribute most to the doses. This would particularly be the case as the contamination occurred in rainfall. Exactly how much each of these surface types contribute depends on the sizes and locations of the surfaces in relation to the location where people spend time. To assess this, a detailed model would be required. From the scenario described in Section 7.1, city gardens are the surfaces that have been most affected. Management options are required to reduce doses from these contaminated surfaces.
2	**Refer to selection tables for specific surfaces (Table 6.2 - Table 6.5). These selection tables provide a list of all of the applicable management options for the surfaces selected.**
	The relevant selection table is Table 6.4 which lists all 19 applicable management options for soils, grass and plants. For ease of reference it is reproduced here in Table 7.2. Various options can be eliminated immediately. Snow removal would not be required for the time of year of the accident (June). Furthermore, at the predicted level of dose (< 10 mSv in the first year) permanent relocation would not be justified. Temporary relocation could be considered to allow the more disruptive options to be carried out, but conversely, there may be competing factors which make it preferable to leave people in the area. If management options are going to be carried out while people are still in-situ, the impact on those people needs to be considered (see Section 2.4). Restricting public access and restricting workforce access to non-residential areas are not appropriate as city gardens are in residential areas. The following options are not be relevant to city gardens because they can only be implemented in large open spaces due to the scale of the equipment used: ploughing, deep ploughing and skim and burial ploughing A revised selection table (Table 7.3) has been produced to reflect only those options that might be appropriate. The 12 options include 7 for shielding and 5 for removal. Subsequent steps will investigate whether any further options can be eliminated.
3	**Refer to look-up Table 6.6 showing applicability of management options for each radionuclide being considered**
	The relevant data for^{137}Cs are summarised in Table 7.4. These data have been used to eliminate options from the selection tables that are not applicable to^{137}Cs. Only 1 management option listed in Table 7.3 could be eliminated on the basis of it being targeted at radionuclides that pose a resuspension hazard (tie-down). Subsequent steps will endeavour to eliminate further options which are not applicable to this scenario.
4	**Refer to look-up table Table 6.7 showing a checklist of key constraints for each management option**
	The key constraints for the remaining 11 management options are summarised in Table 7.5. The following options can be eliminated: • Turf harvesting: equipment for small scale use in gardens precludes this management option. • Cover grass and soil areas with asphalt: acceptability is likely to be low, thereby eliminating this option. • Cover with clean soil: very large quantities of soil would be needed (up to 10cm) for this option to be effective, thereby eliminating this option. • Triple digging: very slow work rate, unlikely to be carried out for lots of gardens The selection table for city gardens has been revised to show the 7 remaining management options that have still to be considered (Table 7.6).
5	**Refer to look-up Table 6.8 showing effectiveness of management options**
	Information presented in Table 6.8 that is relevant to the 7 remaining management options is summarised in Table 7.7. The following options can be eliminated: • Grass cutting: not effective in reducing doses following wet deposition. • Plant and shrub removal: small reduction in dose compared to other removal options.
6	**Refer to look-up Table 6.9 which shows quantities and types of waste produced from implementation of management options**

Table 7.1 Steps involved in selecting and combining options for city gardens contaminated with ^{137}Cs

Step	Action	
	Information on which of the remaining 5 management options generate waste is summarised in Table 7.8. Only 2 options generate waste. These involve the removal of turf and topsoil (manual and mechanical) which both produce 60-70 kg m^{-2} waste in the form of soil and turf. Implementation of these options would require an agreed waste management strategy and the quantities of waste may be prohibitive if the option is implemented on a large scale.	
7	**Refer to individual datasheets (Section 3) for all options remaining in the selection table and note the relevant constraints**.	
	The final selection table for the 5 remaining management options is presented in Table 7.9. A detailed analysis of all remaining options by careful consideration of the relevant datasheets is required. It can only be done on a site specific basis and in close consultation with the affected local population and other stakeholders to take into account local circumstances.	
8	**Based on Steps 1-7, select and combine options that should be considered as part of the recovery strategy.**	
	The following options could be considered for reducing doses from city gardens contaminated with ^{137}Cs. Manual digging and rotovating do not generate waste and are less disruptive than topsoil and turf removal, which would be difficult to justify on a large scale at this level of dose. However, the implementation of these 'removal' options in small 'sensitive' areas within the city, such as play areas and land around schools and nurseries may be appropriate. It may be that doing no clean up is justified, in which case there would need to be a good communication with the local community and a rigorous monitoring strategy to provide reassurance and to demonstrate that the risks are low.	
	Option	Comments
	Temporary relocation	Consider this while other options are being carried out
	Manual digging	Loss of amenity in short-medium term. Garden will need to be replanted or reseeded. More effective in reducing doses than rotovating but slower to implement.
	Rotovating (mechanical digging)	Loss of amenity in short-medium term. Garden will need to be replanted or reseeded. Relatively quick to do and equipment available. No waste generated but mixing contamination within the soil would compromise any subsequent soil removal. Leaving contamination in-situ may not be acceptable to home owners.
	Topsoil and turf removal (manual)	Loss of amenity in short-medium term. Soil will have to be replaced and garden replanted or reseeded. Large quantise of waste and waste disposal route or management strategy required.
	Topsoil and turf removal (mechanical)	Loss of amenity in short-medium term. Soil will have to be replaced and garden replanted or reseeded. Large quantise of waste and waste disposal route or management strategy required.

Go to greyscale table

Table 7.2 Selection table of management options for soils, grass and plants

When to apply	Early (E) (days-weeks)	Medium-Long (M/L) (months-years)
Restrict access		
Permanent relocation from residential areas (8)	🟫	🟫
Prohibit public access to non-residential areas (9)	🟨	🟫
Restrict workforce access (time or personnel) to non-residential areas (10)	🟨	🟫
Temporary relocation from residential areas (11)*	🟨	🟫
All open spaces		
Cover grassed and soil surfaces (e.g. with asphalt) (35)	🟫	🟫
Cover with clean soil (36)	🟨	🟨
Grass cutting and removal (38)	🟩	🟥
Plant and shrub removal (40)	🟨	🟥
Snow removal (50)	🟨	🟥
Tie-down (44)	🟫	🟥
Topsoil and turf removal (manual) (45)	🟥	🟫
Topsoil and turf removal (mechanical) (46)	🟥	🟫
Turf harvesting (48)	🟨	🟨
Small open spaces (e.g. gardens)		
Manual digging (39)	🟨	🟨
Rotovating (42)	🟨	🟨
Triple digging (47)	🟥	🟥
Large open spaces (e.g. parks, countryside)		
Deep ploughing (37)	🟨	🟨
Ploughing (41)	🟩	🟩
Skim and burial ploughing (43)	🟥	🟨

Key:

🟩	Recommended with few constraints
🟨	Recommended but requires further evaluation to overcome some constraints
🟫	Economic or social constraints exist, requiring full analysis and consultation period.
🟥	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Notes:

* Only while options in gardens are being implemented

Go to greyscale table

Table 7.3 Selection table of management options for soils, grass and plants

When to apply	Early (E) (days-weeks)	Medium-Long (M/L) (months-years)
Restrict access		
Temporary relocation from residential areas (11)*	🟨	🟫
All open spaces		
Cover grassed and soil surfaces (e.g. with asphalt) (35)	🟫	🟫
Cover with clean soil (36)	🟨	🟨
Grass cutting and removal (38)	🟩	🟥
Plant and shrub removal (40)	🟨	🟥
Tie-down (fixing contamination to the surface) (44)	🟫	🟥
Topsoil and turf removal (manual) (45)	🟥	🟫
Topsoil and turf removal (mechanical) (46)	🟥	🟫
Turf harvesting (48)	🟨	🟨
Small open spaces (e.g. gardens)		
Manual digging (39)	🟨	🟨
Rotovating (mechanical digging) (42)	🟨	🟨
Triple digging (47)	🟥	🟥

Key:

🟩	Recommended with few constraints
🟨	Recommended but requires further analysis to overcome some constraints
🟫	Economic or social constraints exist, requiring full analysis and consultation period.
🟥	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Notes:

* Only while options in gardens are being implemented

Table 7.4 Step 3 – Applicability of remaining management options* for ^{137}Cs

Restrict access	
Temporary relocation from residential areas (11)	✓
Soil, grass and plants	✓
Cover grassed and soils surfaces (e.g. with asphalt) (35)	✓
Cover with clean soil (36)	✓
Grass cutting and removal (38)	✓
Manual digging (39)	✓
Plant and shrub removal (40)	✓
Rotovating (mechanical digging) (42)	✓
Tie-down (fixing contamination to the surface) (44)	a
Topsoil and turf removal (manual) (45)	✓
Topsoil and turf removal (mechanical) (46)	✓
Triple digging (47)	✓
Turf harvesting (48)	✓

Key:

✓: Selected as target radionuclide (i.e. known or probable applicability, see Section 6.3)

a: This management option reduces doses from inhalation of resuspended material which would not normally be an important pathway for this radionuclide

Notes:

*****: Only options listed in selection table for soil and grass and plants are shown

Table 7.5 Step 4 – Checklist of key constraints to consider for remaining management options

Restrict access	Key constraints
Temporary relocation from residential areas (11)	Alternative accommodation
	Not applicable for timescales > 1 year
	Infrastructure to support relocated populations
Soil, grass and plants	
Cover grassed and soils surfaces (e.g. with asphalt) (35)	Severe cold weather (frost or snow)
	Complicates further options involving removal of soil
	Acceptability in gardens likely to be low
	Use on small areas only
	Use in conservation areas / historic sites
	Steep slope
Cover with clean soil (36)	Use on listed or historic sites or in conservation area
	Very large quantities of soils required
	Complicates further options involving removal of soil
	Loss of plants and shrubs
Grass cutting and removal (38)	Needs to be implemented quickly and before rain
	PPE required as dust suppression not possible
	Steep slopes
	Need grass mowers with collection boxes
Manual digging (39)	Severe cold weather (frost or snow)
	Use in conservation areas / historic sites
	Area must not have been tilled since deposition
	Area must mot be re-dug
	Complicates further options involving removal of soil
	Use on small areas only
	Slow work rate[c]
Plant and shrub removal (40)	Severe cold weather (frost or snow)
	Needs to be implemented quickly and before rain
	Dependent on time of year. Only if leaves on plants and shrubs
	PPE required as dust suppression not possible
	Use in conservation areas / historic sites
Rotovating (mechanical digging) (42)	Severe cold weather (frost or snow)
	Use on small areas only
	Area must mot be re-dug
	Area must not have been tilled since deposition
	Use in conservation areas / historic sites
	Complicates further options involving removal of soil
Topsoil and turf removal (manual) (45)	Severe cold weather (frost or snow)
	Soil texture (not appropriate for stony soils)
	Use in conservation areas / historic sites
	Large amounts of waste
	Use on small areas only
	Slow work rate
	Large team required if reseed or returf

Table 7.5 Step 4 – Checklist of key constraints to consider for remaining management options

Restrict access	Key constraints
Topsoil and turf removal (mechanical) (46)	Severe cold weather (frost or snow)
	Soil texture (not appropriate for stony soils)
	Use in conservation areas / historic sites
	Tie-down needed to suppress dust
	Large amounts of waste
	Large team required if returf or reseed
Triple digging (47)	Severe cold weather (frost or snow)
	Area must not have been tilled since deposition
	Area must mot be re-dug
	Use in conservation areas / historic sites
	Use on small areas only
	Complicates further options involving removal of soil
	Very slow work rate
Turf harvesting (48)	Availability of equipment
	Rocky areas / uneven ground
	Large amounts of waste
	Tie-down needed to suppress dust
	Severe cold weather (frost or snow)

Go to greyscale table

Table 7.6 Selection table of management options for soils, grass and plants

When to apply	Early (E) (days-weeks)	Medium-Long (M/L) (months-years)
Restrict access		
Temporary relocation from residential areas (11)*	🟨	🟫
All open spaces		
Grass cutting and removal (38)	🟩	🟥
Plant and shrub removal (40)	🟨	🟥
Topsoil and turf removal (manual) (45)	🟥	🟫
Topsoil and turf removal (mechanical) (46)	🟥	🟫
Small open spaces (e.g. gardens)		
Manual digging (39)	🟨	🟨
Rotovating (mechanical digging) (42)	🟨	🟨

Key:

🟩	Recommended with few constraints
🟨	Recommended but requires further analysis to overcome some constraints
🟫	Economic or social constraints exist, requiring full analysis and consultation period.
🟥	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Notes:

* Only while options in gardens are being implemented

Table 7.7 Effectiveness of management options for ^{137}Cs

Management option	Effectiveness in reducing external gamma doses	Comments
Restrict access		
Temporary relocation from residential areas (11)	Up to 100% reduction in dose (all pathways) while individual is away from affected area.	-
Soil, grass and plants		
Grass cutting and removal (38)	20-25% reduction in external gamma dose if dry deposition (negligible reduction if wet deposition).	Effectiveness is significantly reduced after rain has occurred or if grass has been already cut post deposition.
Plant and shrub removal (40)	10-15% reduction in external gamma dose.	Effectiveness is significantly reduced after rain has occurred. Only effective before foliage dies back in autumn/winter.
Manual digging (39)	20-25% reduction in external gamma dose if dry deposition (25-30% reduction if wet deposition).	Effectiveness depends on the success of mixing within the soil. Dose rate reductions are likely to be higher than those for mechanical digging since rotovation does not bury contamination under a clean soil layer but mixes (dilutes) it homogeneously over the treated depth.
Rotovating (mechanical digging) (42)	10-15% reduction in external gamma dose if dry deposition (15-20% reduction if wet deposition).	Effectiveness depends on the success of mixing within the soil. Dose rate reductions are likely to be less than those for manual digging since rotovation does not bury contamination under a clean soil layer but mixes (dilutes) it homogeneously over the treated depth.
Topsoil and turf removal (manual) (45) Topsoil and turf removal (mechanical) (46)	35-40% reduction in external gamma dose if dry deposition (40-45% reduction if wet deposition).	The removal depth needs to be chosen to ensure maximum removal of contamination in order to achieve maximum effectiveness. If a standard removal depth is used, the effectiveness will reduce in time after this as contamination migrates to deeper soil depths.

Table 7.8 Quantities and types of waste produced by the management options[*]

Management option	Waste arising (kg m^{-2} unless otherwise stated) [#]	Waste material
Restrict access		
Temporary relocation from residential areas (11)	None	
Soil, grass and plants		
Manual digging (39)	None	
Rotovating (mechanical digging) (42)	None	
Topsoil and turf removal (manual) (45)	60 – 70 (5 cm depth removed)	Soil and turf
Topsoil and turf removal (mechanical) (46)	60 – 70 (5 cm depth removed)	Soil and turf

Notes:

[*] All values are for illustrative purposes to enable the impact of the implementation of the various options to be scoped and a comparison across options to be made.

[#] No collection of waste and segregation assumed unless stated. If waste materials can be segregated into contaminated and exempt waste, quantities of contaminated waste will be much smaller. For example, water can be collected, filtered and re-used.

Go to greyscale table

Table 7.9 Selection table of remaining management options for city gardens

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Temporary relocation from residential areas (11)*	🟨	🟫
City gardens		
Manual digging (39)	🟨	🟨
Rotovating (mechanical digging) (42)	🟨	🟨
Topsoil and turf removal (manual) (45)	🟥	🟫
Topsoil and turf removal (mechanical) (46)	🟥	🟫

Key:

🟩	Recommended with few constraints
🟨	Recommended but requires further analysis to overcome some constraints
🟫	Economic or social constraints exist, requiring full analysis and consultation period.
🟥	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Notes:

* Only while options in gardens are being implemented

7.2 Example 2 – Small scale incident involving the dispersion of ^{239}Pu

Scenario

- Small scale incident on 1st September
- Release of radioactivity into the commercial district of a town (shops and offices)
- Rain at the time of deposition

Current situation

- The population has been evacuated to a distance of 500 m in all directions

7.2.1 Decision framework for developing a recovery strategy

It is first necessary to consult the decision tree for developing a recovery strategy: characterisation of accident, monitoring and doses Figure 6.1.

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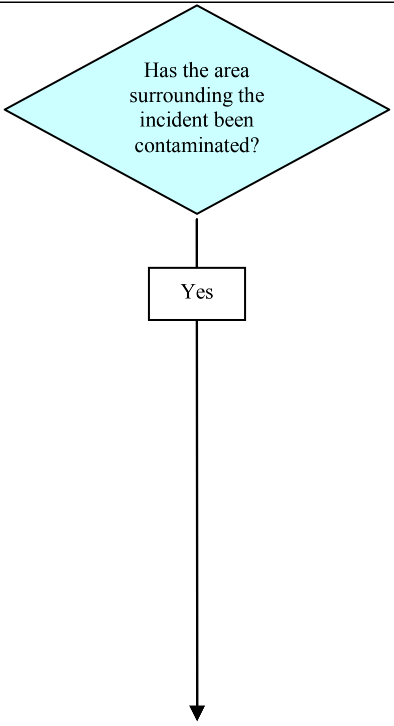
<td> </td>
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- Scope the nature of contamination in the inhabited area. Refer to Section 1.9. for guidance.
- Consult Section 1.7 to find out what hazard ^{239}Pu presents. Table 1.1 shows that ^{239}Pu mainly emits long-lived alpha radiation and some gamma radiation. The exposure pathway of concern is inhalation of resuspended contaminated dust in the environment.
- Monitoring*:* ^{239}Pu emits alpha particles which have a very short range in any material, including air, and their measurement is more difficult than for gamma and beta emitters. Furthermore, the gamma radiation emitted by ^{239}Pu is generally of very low intensity and energy; it would be very difficult to rapidly monitor the area to identify the extent of the contamination. This delay and uncertainty would need to be taken into account throughout the development and implementation of the recovery strategy.

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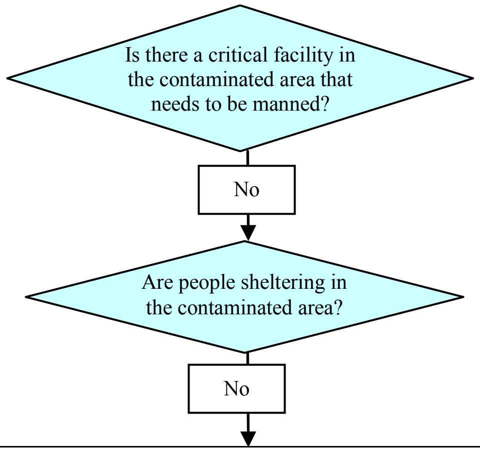
<td>
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- The affected area is a small section of a commercial district with shops and offices. None are critical facilities.
- There is no sheltering in place in the area; everyone was evacuated. Therefore disruption shouldn't be an issue when implementing the management options. However, there is likely to be pressure to complete work quickly in order for economic activities to restart as soon as possible.

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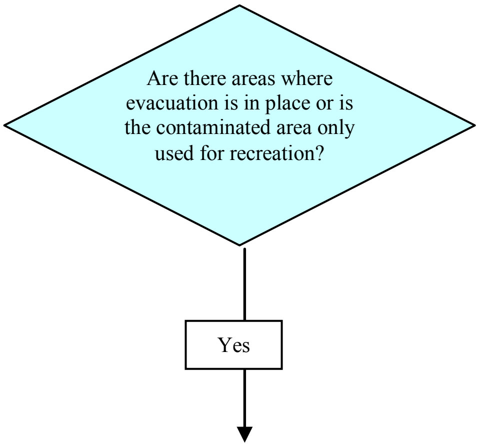
<td>
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- Evacuation should be maintained until monitoring of the area has taken place and an estimate of long-term doses be carried out. In this case, due to the long timescales for monitoring of plutonium, it is likely that models will be used to justify the need to maintain evacuation.
- This approach needs to be balanced against the pressure to return people to the area as soon as possible. Because it is not a residential area, the disadvantages of a prolonged evacuation are not likely to be as pronounced.

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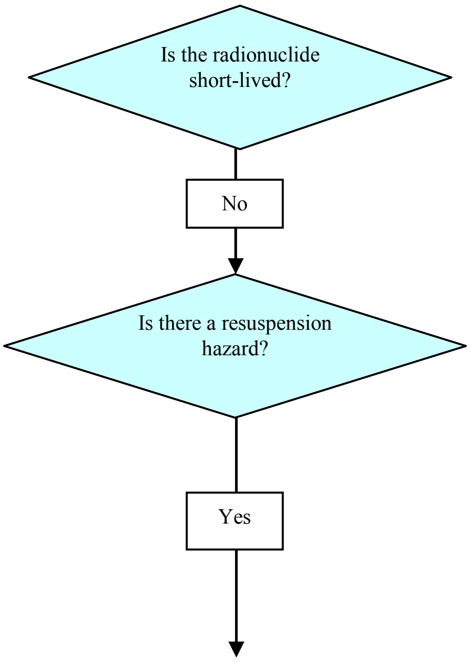
<td>
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<td>

- ^{239}Pu gives rise to a long-lived resuspension hazard. Management options need to be selected appropriate to this hazard.
- The main radiological concern would be to avoid inhalation of resuspended material. Tie-down (fixing) options should be considered in the short-term. Temporary fixing materials can be applied cheaply and quickly and can be used to prevent further spread of contamination in the environment. They can also help to protect workers monitoring in the area.
- In wet weather, the use of fixing materials is limited. Temporary materials, such as water and sand, are ineffective because the wet weather conditions will suppress resuspension and remove a lot of the loose contamination on the surface. The use of bitumen spray and paints could be considered once surfaces have dried.

</td>
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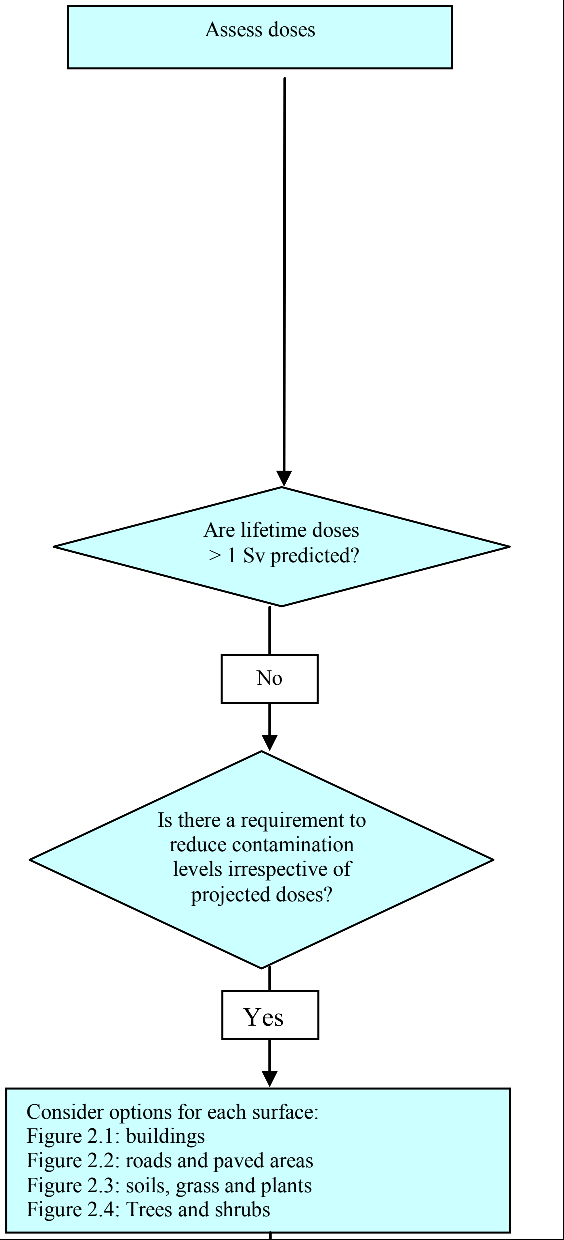
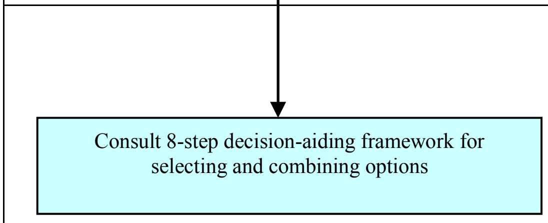
</table>

	• Due to the short range of alpha radiation from ^{239}Pu, problems only arise if the contaminants enter the human body. The most important exposure pathway is inhalation, particularly from resuspended material on contaminated surfaces. • Section 1.12 on estimating doses in inhabited areas refers the user to Appendix B for further information on calculating the doses. Appendix B4 contains specific information about inhalation of resuspended material. Table B4 contains data to estimate the committed effective dose from resuspended material. • For this scenario, it is assumed that lifetime doses from resuspension are very low. • Given the nature of the affected area, it is probable that doses will not be the key determining factor for reducing contamination levels and there is likely to be pressure to reduce contamination levels in the environment irrespective of doses. If people are expected to return to the area to work and shop, they will need reassurance that it is safe to do so. This could include seeing that contamination levels had been reduced to a level as low as possible rather than to a level set on purely radiological protection grounds.
	• The 8-step decision-aiding framework described in Section 6.1 and presented below in Table 7.10 should now be consulted for selecting and combining management options for each contaminated surface.

7.2.2 Choosing management options

For the purposes of this example, it is assumed that only external building surfaces are considered further. Justification for this choice is given in step 1 in Table 7.10. In reality, the decision making process would be much more complicated. Options would need to be assessed for all surfaces in the inhabited area. This would take into account, for example, resource implications, quantities of waste, constraints on implementation, and social impact.

The development of a recovery strategy for buildings makes use of the decision framework described in Section 6. Before going through the generic steps involved in selecting and combining options it is important for users to appreciate that when using the Inhabited Areas Handbook to develop a recovery strategy they should establish a dialogue with national and local stakeholders; be familiar with the structure and content of the Handbook; develop knowledge of technical information underpinning a recovery strategy and an understanding of the factors influencing implementation of options and selection of a strategy (Section 4).

Short-term tie-down options have already been identified as a potential strategy for preventing resuspension of radioactive material. In this scenario, there is pressure to remove ^{239}Pu from the contaminated environment and therefore permanent fixing options may not be acceptable to the public. In the longer term, consideration would need to be given to the selection of management options that remove contamination from the surfaces in this commercial district as well as fixing options. It will be extremely important to involve all stakeholders in the decisions.

The development of a recovery strategy for external building surfaces using the accident scenario for ^{239}Pu is described in Table 7.10 below, based on the eight generic steps described in Section 6.1. The numbers in brackets in Tables 7.11 – 7.17 refer to the datasheet number.

Table 7.10 Steps involved in selecting and combining options for external building surfaces contaminated with ^{239}Pu

Step	Action
1	**Identify one or more surfaces that are likely to be/have been contaminated**
	Using Table B5, it is possible to estimate the likely levels of contamination on other surfaces in the area. This provides an indication of the surfaces that are likely to have received the most contamination. Using this information, contaminated soil/grass areas, trees and roofs and streets could be expected to contribute most to resuspension doses. Exactly how much each of these surface types would contribute depends on the sizes and locations of the surfaces in relation to the location where people spend time. To assess this, a detailed model would be required. For this scenario (described in Section 7.2), external building surfaces, particularly roofs have been identified as being of concern. Management options may be required to reduce resuspension doses from these contaminated surfaces; however, doses from this exposure pathway have been estimated to be low. The scenario also indicates that there is pressure to remove plutonium contamination from the area so it is likely that all surfaces will need to be considered, particularly those that are considered as sensitive.
2	**Refer to selection tables for specific surfaces (Table 6.2 - Table 6.5). These selection tables provide a list of all of the applicable management options for the surfaces selected.**
	The relevant selection table is Table 6.2 which lists all applicable management options for buildings. For ease of reference it is reproduced here in Table 7.11. However many of these 30 options are either not relevant to external surfaces or to the time of year (i.e. no snow present in September). Also as it is the commercial district that is affected, there are no wooden buildings present, making mechanical abrasion of wooden walls unnecessary. Furthermore, at the predicted level of dose (< 10 mSv in the first year) permanent relocation would not be justified. This is not a residential area, so access can be restricted. Because members of the public will not be present, more disruptive and dust-producing options could be considered. It is important that the workers implementing these options are adequately protected (Section 4.3) and that measures are put in place to prevent the further spread of contamination in the environment. Whilst the area remains empty, security will need to be maintained. Empty premises may become a target for looters and thieves. A revised selection table (Table 7.12) has been produced to reflect only those options that might be appropriate for external building surfaces. Shielding options have been eliminated because of public and political pressure to remove contamination from the area for this scenario. The 9 remaining options include 1 for restricted access and 8 for removal. Subsequent steps will investigate whether any further options can be eliminated.
3	**Refer to look-up Table 6.6 showing applicability of management options for ^{239}Pu**
	The relevant data for ^{239}Pu are summarised in Table 7.13. These data have been used to eliminate options from the selection tables that are not applicable to ^{239}Pu. Only 1 management option listed in Table 7.9 could be eliminated on the basis of it being targeted at radiocaesium (treat walls with ammonium nitrate).
4	**Refer to look-up table Table 6.7 showing a checklist of key constraints for each management option**
	The key constraints for the remaining 8 management options are summarised in Table 7.14. The availability of equipment for sandblasting, roof cleaning and roof brushing may be limited, although these options have been retained.
5	**Refer to look-up Table 6.8 showing effectiveness of management options**
	Information presented in Table 6.8 that is relevant to the remaining management options is summarised in Table 7.15. Rainfall at the time of the incident means that any contamination could be more strongly fixed to particular surfaces than if it had been dry. Therefore, only options which remove well-fixed contamination are applicable. Unlike high pressure hosing, firehosing is likely to be ineffective in removing the contamination. This management option has been eliminated therefore.
6	**Refer to look-up Table 6.9 which shows quantities and types of waste produced from implementation of management options**
	Information on which of the 7 remaining management options generate waste is summarised in Table 7.16. All options except restricting public access produce waste. Two options produce large volumes of waste; roof replacement (20-50 kg m^{-2}) and sandblasting (50 litres m^{-2}). The implementation of these options would require an agreed waste management strategy.
7	**Refer to individual datasheets (Section 3) for all options remaining in the selection table and note the relevant constraints**.
	The final selection table for the 7 remaining management options is presented in Table 7.17. A detailed analysis of all remaining options by careful consideration of the relevant datasheets is required. It can only be done on a site specific basis and in close consultation with the affected local population and other stakeholders to take into account local circumstances.

Table 7.10 Steps involved in selecting and combining options for external building surfaces contaminated with ^{239}Pu

Step	Action	
8	**Based on Steps 1-7, select and combine options that should be considered as part of the recovery strategy.**	
	The following options could be considered to reduce doses from external building surfaces contaminated with ^{239}Pu. However, other than restricting public access, they are all options which would not be recommended to reduce resuspension doses alone, particularly as building surfaces do not contribute to the overall resuspension doses received (see Table 7.15). If selected, these options would be carried out for reasons other than radiological protection (i.e. public perception, political pressure). Options for specialised surfaces could be considered but some of these require specialised equipment and chemicals which may not be available. It may be that doing no clean up is justified, in which case there would need to be a good communication with the local community and a rigorous monitoring strategy to provide reassurance and to demonstrate that the risks are low.	
	Option	Comments
	Restrict public access	
	High pressure hosing	This option requires specialist equipment. It may give rise to an increased resuspension hazard.
	Peelable coatings	This option is only suitable for small areas, because it is difficult to remove the coating intact when applied to large surfaces. It works best when applied to smooth surfaces that could be found on buildings in a commercial district.
	Roof brushing	This option requires specialist equipment that may not be available. It also leads to an increased resuspension hazard.
	Roof cleaning with pressurised hot water	This option requires specialist equipment that may not be available. Large volumes of liquid waste are produced.
	Roof replacement	This is a very disruptive option, which would only be justified if the contamination levels and subsequent doses to people working in the area are > 10 mSv in the first year. Large volumes of solid waste are produced.
	Sandblasting walls	This is a very disruptive option that requires specialist equipment. It could also have a negative aesthetic impact on the buildings. It will also give rise to an increased resuspension hazard during implementation

Go to greyscale table

Table 7.11 Selection table of management options for buildings

When to apply	Early (E) (days-weeks)	Medium-Long (M/L) (months-years)
Restrict access		
Permanent relocation from residential areas (8)	🟫	🟫
Prohibit public access to non-residential areas (9)	🟨	🟫
Restrict workforce access (time or personnel) to non-residential areas (10)	🟨	🟫
Temporary relocation from residential areas (11)	🟨	🟫
External surfaces		
Demolish buildings (12)	🟫	🟫
Firehosing (13)	🟩	🟥
High pressure hosing (14)	🟥	🟥
Mechanical abrasion of wooden walls (15)	⬜	⬜
Peelable coatings (49)	🟨	🟥
Roof brushing (16)	🟨	🟨
Roof cleaning with pressurised hot water (17)	🟨	🟨
Roof replacement (18)	🟫	🟫
Sandblasting (19)	🟥	🟥
Snow removal (50)	🟨	🟥
Tie down (fixing contamination to the surface) (20)	🟨	🟥
Treatment of walls with ammonium nitrate (21)	🟨	🟥
Indoor surfaces and objects		
Other cleaning methods (scrubbing, shampoo, steam cleaning) (23)	🟩	🟥
Removal of furniture, soft furnishings and other objects (24)	🟨	🟨
Surface removal (25)	🟨	🟨
Vacuum cleaning (26)	🟩	🟩
Washing (27)	🟩	🟥
Public buildings (e.g. railway stations)		
Aggressive cleaning of indoor contaminated surfaces (22)	🟨	🟨
Precious objects and personal items		
Storage, shielding, covering, gentle cleaning of precious objects (28)	🟩	🟫
Specialised surfaces in industrial buildings		
Application of detachable polymer paste on metal surfaces (53)	🟩	🟥
Chemical cleaning of metal surfaces (54)	🟨	🟥
Chemical cleaning of plastic and coated surfaces (55)	🟨	🟥
Cleaning of contaminated (industrial) ventilation systems (56)	🟨	🟨
Electrochemical cleaning of metal surfaces (57)	🟨	🟥
Filter removal (58)	🟩	🟩
Ultrasound treatment with chemical decontamination (59)	🟨	🟥

Key:

🟩	Recommended with few constraints
🟨	Recommended but requires further evaluation to overcome some constraints
🟫	Economic or social constraints exist, requiring full analysis and consultation period.
🟥	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to greyscale table

Table 7.12 Selection table of management options for external building surfaces

When to apply	Early (E) (days-weeks)	Medium-Long (M/L) (months-years)
Restrict access		
Prohibit public access to non-residential areas (9)	🟨	🟫
External surfaces		
Firehosing (13)	🟩	🟥
High pressure hosing (14)	🟥	🟥
Peelable coatings (49)	🟨	🟥
Roof brushing (16)	🟨	🟨
Roof cleaning with pressurised hot water (17)	🟨	🟨
Roof replacement (18)	🟫	🟫
Sandblasting (19)	🟥	🟥
Treatment of walls with ammonium nitrate (21)	🟨	🟥

Key:

🟩	Recommended with few constraints
🟨	Recommended but requires further analysis to overcome some constraints
🟫	Economic or social constraints exist, requiring full analysis and consultation period.
🟥	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Table 7.13 Step 3 – Applicability of remaining management options* for ^{239}Pu

Restrict access	
Prohibit public access to non-residential areas (9)	✓
External surfaces	
Firehosing (13)	✓
High pressure hosing (14)	✓
Peelable coatings (49)	✓
Roof brushing (16)	✓
Roof cleaning with pressurised hot water (17)	✓
Roof replacement (18)	✓
Sandblasting (19)	✓
Treatment of walls with ammonium nitrate (21)	a

Key:

✓: Selected as target radionuclide (i.e. known or probable applicability, see Section 6.3)

a. This management option is targeted specifically at radiocaesium

Notes:

*****: Only options listed in selection table are for buildings

Table 7.14 Step 4 - Checklist of key constraints to consider when selecting management options

Restrict access	Key constraints
Prohibit public access to non-residential areas (9)	Enforcement (total prohibition needed)
Buildings	
Firehosing (13)	Severe cold weather
	Damage (flooding)
	Needs to be implemented quickly and before rain
	Use on historic and listed buildings
	Walls and roofs must be resistant to water at high pressure
High pressure hosing (14)	Severe cold weather
	Damage (flooding)
	Use on historic and listed buildings
	Walls and roofs must be resistant to water at high pressure
Peelable coatings (49)	Severe cold weather, wet weather
	Use on small areas only
	Materials not widely available
	Use on listed and historic buildings
Roof brushing (16)	Severe cold weather
	Use on historic and listed buildings (potential damage)
	Availability of equipment
	Slow work rate
Roof cleaning with pressurised hot water (17)	Severe cold weather
	Roof construction must resist water at high pressure
	Availability of equipment
	Slow work rate
	Use on listed and historic buildings (potential damage)
Roof replacement (18)	Use on listed and historic buildings
	Large amount of waste
	Access
	Building materials, e.g. asbestos
	Slow work rate
Sandblasting (19)	Use on listed and historic buildings
	Large team size
	Damage to surfaces
	Surfaces need to be resistant to high water pressure
	Severe cold weather

Table 7.15 Step 5 - Effectiveness of management options for ^{239}Pu

Management option	Effectiveness in reducing resuspension doses and/or contamination on surface	Comments
Restrict access		
Prohibit public access to non-residential areas (9)	Up to 100% reduction in dose (all pathways) from areas where access is prohibited	Particularly useful for short-lived radionuclides. Effectiveness depends on individuals complying. Will not reduce contamination levels in the environment
Buildings		
Firehosing (13)	Negligible reduction in overall resuspension dose. A decontamination factor (DF) of 1.3 can be achieved if implemented within 1 week of deposition and before significant rain.	Repeated application is unlikely to provide any significant increase in DF.
High pressure hosing (14)	< 5% reduction in overall resuspension doses A decontamination factor (DF) of 1.3 can be achieved if implemented within 1 week of deposition and before significant rain.	**Unlikely to be considered for reducing resuspension doses alone.** Repeated application is unlikely to provide any significant increase in DF.
Peelable coatings (49)	Negligible reduction in overall resuspension dose. Decontamination factor (DF) of up to 5 if implemented within a few weeks. While the peelable coating is in place, resuspended activity in air above the surface will be reduced by almost 100%.	This option is likely to be most effective when used on smooth surfaces. Later application is likely to give a lower DF, particularly on porous building materials such as bricks and tiles.
Roof brushing (16)	Negligible reduction in overall resuspension dose. Decontamination factor (DF) of 2 – 7	**Unlikely to be considered for reducing resuspension doses alone.** Repeated application is unlikely to provide any significant increase in DF.
Roof cleaning with pressurised hot water (17)	Negligible reduction in overall resuspension dose. A decontamination factor (DF) of 2 – 7 could be achieved if implemented soon after deposition (DF of 2 – 4 after 10 years).	**Unlikely to be considered for reducing resuspension doses alone.** If a surface layer of moss/algae covers the roof at the time of deposition, almost all the contamination may be removable.
Roof replacement (18)	Negligible reduction in overall resuspension dose. All contamination from roof removed	**Unlikely to be considered for reducing resuspension doses alone.**
Sandblasting (19)	Negligible reduction in overall resuspension dose. Decontamination factor (DF) of 4 – 10 could be achieved if implemented soon after deposition (will decrease with time).	**Unlikely to be considered for reducing resuspension doses alone.** Repeated application is unlikely to provide any significant increase in DF.

Table 7.16 Quantities and types of waste produced by the management options[*]

Management option	Waste arising (kg m^{-2} unless otherwise stated) [#]	Waste material
Restrict access		
Prohibit public access to non-residential areas (9)	None	
Buildings		
High pressure hosing (14)	0.2 – 0.4	Dust
	20 litres m^{-2}	Water
Peelable coatings (49)	1	Rubber-like material
Roof brushing (16)	0.2 – 0.6	Dust and moss
	15 litres m^{-2}	Water
Roof cleaning with pressurised hot water (17)	0.2	Dust and moss
	30 litres m^{-2}	Water
Roof replacement (18)	20 – 50	Roofing material
Sandblasting (19)	3	Dust and sand
	50 litres m^{-2}	Water

Notes:

[*] All values are for illustrative purposes to enable the impact of the implementation of the various options to be scoped and a comparison across options to be made.

[#] No collection of waste and segregation assumed unless stated. If waste materials can be segregated into contaminated and exempt waste, quantities of contaminated waste will be much smaller. For example, water can be collected, filtered and re-used.

Go to greyscale table

Table 7.17 Selection table of management options for external building surfaces

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Prohibit public access to non-residential areas (9)	🟨	🟫
External surfaces		
High pressure hosing (14)	🟥	🟥
Peelable coatings (49)	🟨	🟥
Roof brushing (16)	🟨	🟨
Roof cleaning with pressurised hot water (17)	🟨	🟨
Roof replacement (18)	🟫	🟫
Sandblasting (19)	🟥	🟥

Key:

🟩	Recommended with few constraints
🟨	Recommended but requires further analysis to overcome some constraints
🟫	Economic or social constraints exist, requiring full analysis and consultation period.
🟥	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

8 GLOSSARY

Term	Definition
Action level	The level of dose rate, activity concentration or any other measurable quantity above which intervention should be undertaken during chronic or emergency exposure.
Activity	The rate at which nuclear decays occur in a given amount of radioactive material. The SI unit for activity is the Becquerel (Bq), defined as one decay per second (1 Bq = 1 s^{-1}).
Activity concentration	The activity per unit mass of a radioactive material. Unit: Bq kg^{-1}.
Alpha particle, α	A particle which consists of two protons and two neutrons (identical to a nucleus of helium). Emitted by the nucleus of a radionuclide during alpha decay.
Beta particle, β	A particle consisting of a fast moving electron or positron. Emitted by the nucleus during beta decay.
Collective dose	The sum of individual doses in a specified population. Often approximated to be the average effective dose in a population exposed to a particular source of ionising radiation multiplied by the number of people exposed. Unit: manSv.
Contamination / radioactive contamination	The deposition of radioactive material on the surfaces in inhabited areas or onto or into drinking water sources and supplies.
Countermeasure	See management option.
Datasheet	A compilation of data and information about a management option designed to support decision-makers in the evaluation of an option and the impact of its implementation.
Decontamination factor (DF)	Effectiveness of a removal option is expressed as a Decontamination Factor (DF). The DF is the ratio of the amount of contamination initially present on a specific surface (e.g. buildings, paved surfaces, grass, soil, and shrubs, etc.) to that remaining after implementing the option. For example, a DF of 5 indicates that 80% of the activity can be removed.
Deterministic effect	Previously known as a non-stochastic effect. A radiation-induced health effect characterised by a severity which increases with dose above some clinical threshold, and above which threshold such effects are always observed. Examples of deterministic effects are nausea and radiation burns.
Dose	General term used for a quantity of ionising radiation. Unless used in a specific context, it refers to the effective dose.
Dose rate	General term used for a quantity of ionising radiation received per unit time. Unless used in reference to a particular organ in the body, it refers to the effective dose rate.
Effective dose	The effective dose is the sum of the weighted equivalent doses in all the tissues and organs of the body. It takes account of the relative biological effectiveness of different types of radiation and variation in the susceptibility of organs and tissues to radiation damage. Unit sievert, Sv.
Emergency phase (early phase)	The time period during which urgent actions are required to protect people from short-term relatively high radiation exposures in the event of a radiological emergency or incident.
Emergency countermeasures	Actions taken during the emergency phase with the aim of protecting people from short-term relatively high radiation exposures, e.g. evacuation, sheltering, taking stable iodine tablets.
Equivalent dose	A quantity used in radiological protection dosimetry, which incorporates the ability of different types of radiation to cause harm in living tissue. Unit sievert, Sv (1Sv = 1 J kg^{-1}).
Gamma ray, γ	High energy photons, without mass or charge, emitted from the nucleus of a radionuclide following radioactive decay, as an electromagnetic wave. They are very penetrating.
Half-life	The time taken for the activity of a radionuclide to lose half its value by decay.

Term	Definition
Incremental dose	The additional dose received by an individual as a result of implementing a management option that specifically does not take into account exposure to activity already present in the environment as a result of deposition of radionuclides on the ground.
Inhabited areas	Places where people spend time (e.g. at home, at work and during recreation).
Ionising radiation	Radiation that produces ionisation in matter. Examples are alpha particles, gamma rays, x-rays and neutrons. When these radiations pass through the tissues of the body, they have sufficient energy to damage DNA.
Isotope	Nuclides with the same number of protons (i.e. same atomic number) but different numbers of neutrons. Not a synonym for nuclide.
Location factor	Ratio of the dose rate determined at a particular location to that in a reference location. Typically used in the estimation of doses to people indoors from measurements made in an outdoor reference location. For example, the dose rate inside a typical residential building could be ten times lower than that above a reference outdoor open grass area; in this case the location factor would have a value of 0.1.
Long-lived radionuclides	Defined for the Handbook as radionuclides with a radioactive half-life greater than three weeks.
Management option	An action, which is part of an intervention, intended to reduce or avert the contamination or likelihood of contamination of food production systems. Previously known as a ‘countermeasure’.
Molecule	The smallest division of a substance that can exist independently while retaining the properties of that substance.
Normal lifestyle	Situation where people can live and work in an area without the radiological emergency and its consequences being foremost in their minds.
Occupancy factor	Fraction of the time spent in a particular location, e.g. inside and outside buildings. Typically used in the estimation of’ normal living’ doses, i.e. taking into account normal day-to-day activities.
Personal protective equipment (PPE)	Equipment worn by a person at work to protect against one or more health or safety risks e.g. safety helmets, gloves, eye protection, high-visibility clothing, safety footwear and safety harnesses.
Photon	A quantum or packet of electromagnetic radiation (e.g. gamma rays or visible light) which may be considered a particle.
Radioactive decay	The process by which radionuclides undergo spontaneous nuclear change, thereby emitting ionising radiation
Radioactivity	The spontaneous emission of ionising radiation from a radionuclide as a result of atomic or nuclear changes. Measured in Becquerels, Bq.
Radiological emergency or incident	Any event, accidental or otherwise, which involves a release of radioactivity into the environment.
Radionuclide	A type of atomic nucleus which is unstable and which may undergo spontaneous decay to another atom by emission of ionising radiation, usually alpha, beta or gamma radiation.
Recovery phase	The time period during which activities focus on the restoration of normal lifestyles for all affected populations. There are no exact boundaries between the emergency phase and the recovery phase. However, within the Handbook the recovery phase should be seen as starting after the incident has been contained.
Recovery strategy	A strategy which aims for a return to normal living. It covers all aspects of the long-term management of the contaminated area and the implementation of specific management options. The development of the strategy should involve all stakeholders.
Respiratory protection	Equipment designed to prevent or reduce the inhalation of radioactive material by individuals.

Term	Definition
Resuspension	A renewed suspension of contaminated particles in the air. The subsequent inhalation of radioactivity is recognised as a potentially significant exposure pathway. Many factors influence resuspension, including climate, wind speed, time since deposition, etc.
Short-lived radionuclides	Defined for the Handbook as radionuclides with a radioactive half-life of less than three weeks.
Sievert	The SI unit of effective dose. Symbol: Sv (1 Sv = 1 J kg^{-1}). The effective dose is commonly expressed in millisieverts (mSv), i.e. one thousandth of one sievert, and microsieverts (μSv), i.e. one thousandth of a millisievert. The average annual radiation dose to the UK population is 2.6 mSv.
Stakeholder	A person or group of persons with a direct or perceived interest, involvement, or investment in something
Stochastic health effect	A radiation induced health effect characterised by a severity which does not depend on dose and for which no lower threshold exists. The probability of such an effect being observed is proportional to the dose. An example of a stochastic effect is cancer.
Surfaces	Examples of surfaces considered in this Handbook include: soil, vegetation and buildings. Management options usually target a specific surface. A surface can have a depth, (e.g. soil) and this can influence the effectiveness of management options in removing contamination from the surface.
Worker	In the Handbook, a worker is defined as an individual who is formally involved with the practical implementation of a recovery strategy. Exposures to workers must be controlled.

APPENDIX A

Types of hazard and radionuclides

A1 GENERAL FACTORS DETERMINING THE HAZARD

Table A1 summarises factors that determine the health hazard to people in connection with exposure to ionising radiation. The most important property of radiation, with respect to the exposure of people, is its ability to penetrate matter that lies between the radioactive source and the person and also within the body. Table A2 describes the different types of radiation that may contribute to the exposure hazard for humans, focussing particularly on their penetrative characteristics. The radionuclides considered in the Handbook have been grouped according to both their physical half-lives and whether their hazard arises predominantly from emissions of gamma rays, beta particles or alpha particles. The half-lives and the most important pathway of exposure based on the radiation emitted for the radionuclides considered are given in Table A3.

Table A1 General factors determining the hazard of exposure to radionuclides

Factor	Explanation
Half-life of radionuclide(s)	Radiation is emitted as the radionuclide decays. The activity of a source is reduced with time, as more and more of the radionuclide decays. The half-life of a radionuclide is the time taken for its activity to decay to half of its original value. Half-lives of different radionuclides can vary between a fraction of a second and millions of years. This means that the radiation from some radionuclides will rapidly reduce to virtually nothing, whereas radiation from others will persist over a very long time.
Type(s) of radiation emitted from the radionuclide(s)	Different radionuclides may emit different types of radiation. Of particular importance in this context are gamma, beta and alpha radiation (see Table A2). Each radionuclide emits radiation with characteristic energies. For a specific type of radiation, the penetration into human tissue increases with the energy. The radiation will, to a varying extent, be weakened by any material present between the radioactive source and the person (e.g. a wall, clothing and even air).
Locations of sources, humans and shielding elements	Hazards may be imposed on humans by internal radiation from radionuclides taken into the body (e.g. after inhalation or ingestion), and/or radiation from sources outside the body. Radionuclides can migrate in the environment (e.g. they may be removed from building surfaces by wind and rain and in some cases be resuspended in the air). This can add to the hazard from inhalation of radionuclides.

Table A2 Descriptions of the different types of radiation that may contribute to the exposure hazard for humans

Radiation type	Description
Alpha particles	An alpha particle consists of two protons and two neutrons (identical to a nucleus of helium) that is emitted by the nucleus of a radionuclide during alpha decay. Alpha particles have a very short range in human tissue. They are generally completely absorbed by a piece of paper or a few centimetres of air (Kaplan, 1979). The human body is protected by a layer of dead skin cells with a thickness of typically 50-80 µm (ICRP, 1992) and alpha particles are generally unable to penetrate this layer. Alpha particles thus only pose a hazard to humans if they are ingested, inhaled or taken in through a wound.
Beta particles	A beta particle consists of a fast moving electron or positron that is emitted by the nucleus of a radionuclide during beta decay. Beta particles can penetrate to significantly greater depth in human tissue than alpha particles. Many beta particles will have sufficient energy to penetrate through the dead skin layer, and can result in skin burns and skin cancer. However, beta particles emitted outside the body can in general not penetrate into the internal human organs. Beta particles can pose a hazard to internal human organs if they are emitted inside the body, e.g. after inhalation, ingestion or through a skin wound. High energy beta particles can have a range of up to a few metres in air. This means that beta particles emitted from contamination on surfaces in the indoor or outdoor environment can contribute to the hazard. A thin layer of clothing between the source and the skin surface can reduce skin penetration considerably. Bremsstrahlung is a secondary radiation which is produced as a reaction in shielding material by beta particles. The majority of Bremsstrahlung rays will have low energy (Gopala et al, 1986) and it is not considered further in the Handbook.
Gamma rays	A gamma ray is a high energy photon without mass or charge, emitted from the nucleus of a radionuclide following radioactive decay. Gamma rays can penetrate through dense structures, including house walls and human bodies. This means that gamma-emitting radionuclides both outside as well as inside the human body can constitute a health hazard.

Table A3 Predominant hazard and half-life for each radionuclide considered in the handbook

	Internal[#]	External[†]			
Radionuclide[*]	Alpha	Beta	Gamma	Half-life	
^{60}Co	-	×	✓	Long	5.27 y
^{75}Se	-	-	✓	Long	119.8 d
^{90}Sr	-	✓	-	Long	29.12 y
^{95}Zr	-	×	✓	Long	63.98 d
^{95}Nb	-	×	✓	Long	66 h
^{99}Mo	-	s	✓	Short	39.28 d
^{103}Ru	-	×	✓	Long	39.28 d
^{106}Ru	-	s	✓	Long	368.2 d
^{131}I	-	×	✓	Short	8.04 d
^{132}Te	-	×	✓	Short	3.26 d
^{134}Cs	-	×	✓	Long	2.062 y
^{136}Cs	-	×	✓	Short	13.1 d
^{137}Cs	-	×	✓	Long	30 y
^{140}Ba	-	×	✓	Short	12.74 d
^{140}La	-	×	✓	Short	1.68 d
^{144}Ce	-	s	✓	Long	284.3 d
^{169}Yb	-	×	✓	Short	32.01 d
^{192}Ir	-	×	✓	Long	74.02 d
^{226}Ra	✓	×	g	Long	1.6 10^3 y

Table A3 Predominant hazard and half-life for each radionuclide considered in the handbook

	Internal#	External†			
Radionuclide*	Alpha	Beta	Gamma	Half-life	
^{235}U	✓	×	g	Long	7.04 10^8 y
^{238}Pu	✓	-	g	Long	87.74 y
^{239}Pu	✓	-	g	Long	2.4 10^4 y
^{241}Am	✓	-	g	Long	432.2 y

Key:

×: minor contribution to exposure. Can be ignored

s: doses to skin may need to be considered

g: minor contribution to exposure from gamma-ray emissions. Can be ignored compared to internal pathway. However, note that if resuspension is stopped through the use of tie-down a small external dose will be received.

Short: half-life < 3 weeks

Long: half-life > 3 weeks

Notes:

*: The ingrowth of all significant radioactive daughters is taken into account

#: Internal doses from resuspension

†: Beta and gamma-ray emitters may also give rise to small resuspension doses

A2 TYPES OF CONTAMINANT

Different types of radiological or nuclear emergencies lead to different types of contaminants released to the atmosphere. The Chernobyl accident, demonstrated that a wide range of radionuclides with different physical and chemical forms can be released from large nuclear power plant accidents (Andersson et al, 2002). For example, radioisotopes of the highly volatile element iodine would be likely to appear in three main physical/chemical forms: as highly reactive elemental iodine vapour; adsorbed on small ambient particles; or in organic gaseous compounds. Other radiologically important, relatively volatile elements (e.g. caesium and ruthenium) would be expected to evaporate during an accident involving high temperatures and form small condensation particles with a size in the range of 0.5-1 µm. Such small particles can travel far in the atmosphere before they are deposited on surfaces in an inhabited environment, since gravitational forces have little impact on them. Radionuclides of more refractory elements, such as strontium, zirconium and cerium, are associated with larger fragmentary particles, and thus are generally deposited at shorter distances. Releases at ground level, for example conventional explosions, may result in the generation of predominantly very large particles which would only remain airborne over rather shorter distances. This was demonstrated by the Thule accident in 1968 (Research Establishment Risø, 1970).

Due to gravity, dry deposition of large particles on horizontal surfaces would be more pronounced than that of small particles. This means that the distribution of small and large particles on the various surfaces in an inhabited area would differ. Although dry deposition can lead to high levels of contamination, it should be noted that particulate contaminants are very effectively washed out from the plume by precipitation. Therefore, areas where it rains during the passage of the contaminated plume typically receive much higher levels of contamination than areas where concentrations of radionuclides in air are similar but it does not rain.

It is often assumed that contamination is homogeneously distributed over a surface. However, various processes can lead to the formation of particularly highly radioactive particles, often termed hot particles. The presence of such particles in the environment can lead to very high local doses. If hot particles may have been deposited in the environment, the possibility of exposure from inhalation, ingestion and skin contamination should always be considered and the likelihood of deterministic effects to the respiratory tract, lower large intestine and the skin evaluated.

A3 GENERAL GUIDANCE ON HAZARDS AND THE USE OF SHIELDING

This section provides some information on the behaviour of beta and gamma emitting radionuclides and whether shielding is likely to be useful in reducing doses. In particular, it provides generic guidance that can be used for radionuclides that are not considered in the Handbook.

A3.1 Beta emitting radionuclides

Beta particles have a well defined range. For energies less than 2.5 MeV, the range, R, of a beta particle of energy E is given empirically by:

$$R = 412\ E^{1.265-0.0954\ln(E)}$$

Where E is the maximum beta energy of the radionuclide (MeV) and R is expressed as a mass thickness in mg cm^{-2}. The mass thickness can be converted into a distance in any material (e.g. air or soil). To convert the range in mg cm^{-2} to a distance in a material (cm), the mass thickness is divided by the density of the material (mg cm^{-3}). For example the range of a beta emitting radionuclide with maximum energy of 1.0 MeV is 412 mg cm^{-2}. The density of air is about 1.3 mg cm^{-3}, which gives a distance range in air of about 3.2 m.

Figure A1 shows the range of beta particles in air as a function of beta energy. This can be used to scope whether beta contamination is likely to be of concern when the location of people relative to the contamination is known.

The effectiveness of materials as a shield against beta emissions depends on the density of the material and its thickness, as described above. A useful tool to estimate the thickness of material needed to give a certain level of shielding as a function of the maximum beta energy of the radionuclide is available in the form of a nomogram (Longworth, 1998). The nomogram is shown in Figure A2. To use the nomogram, for example, to find the absorber thickness required to reduce the dose-rate from a beta emitting radionuclide with a maximum energy 1.0 MeV by 50%, draw a straight line connecting 1.0 MeV through 50% absorption. This intersects the absorber thickness line at about 45 mg cm^{-2}. This would be about a thickness of 20 mm of concrete assuming a density of concrete of 2400 kg m^{-3}. Densities of materials that could be considered as shielding materials in inhabited areas are given in Table A4.

Table A4 Densities of materials that could be used as shielding media

Material	Density, mg cm^{-2}	Relevant option data sheets
Soil	1500	Covering outdoor areas with clean soil
Water	1000	Tie-down (outdoor)
Asphalt	1400	Remove and replace roads etc
Concrete	2400	Remove and replace roads etc
Sand	1600	Tie-down (outdoor)
Polystyrene foam	125	Foam (outdoor)
Rubber	910	Peelable coatings (outdoor)
Bitumen	1000	Tie-down (outdoor)
Perspex	1190	Shielding of precious objects
Paper	1000	Covering indoor surfaces
Paint	1000	Covering indoor surfaces

The ranges of beta particles in some materials that are likely to be used as shielding materials in inhabited areas is also given as a function of beta energy in Figure A3. The value of the range is effectively the thickness of the material needed to stop a beta particle.

As discussed in Section A1 the use of a shielding material on top of the beta contamination increases the intensity of the Bremsstrahlung radiation. The increase is dependent on the shielding material used and is not important for the materials likely to be used. However, if lead or other metals with high atomic numbers and densities are used, Bremsstrahlung doses should be considered, particularly for high energy beta emitters such as ^{90}Sr.

For information, the maximum beta energies for the radionuclides considered in the handbook are given in Table A5. Maximum beta energies were taken from Delacroix et al. (2002), unless otherwise indicated.

Table A5 Maximum beta energies for radionuclides considered in handbook

Radionuclide*	Maximum energy$^{\#}$, MeV
^{60}Co	1.5
^{75}Se	-
^{90}Sr+	2.3
^{95}Zr+	0.4
^{95}Nb	0.16
^{99}Mo+	1.2
^{103}Ru+	0.72
^{106}Ru+	3.5
^{132}Te+	2.1
^{131}I	0.61
^{134}Cs	0.66
^{136}Cs$^{\sim}$	0.66
^{137}Cs	1.2
^{140}Ba+	2.2
^{140}La	2.2
^{144}Ce+	3.0
^{169}Yb	-
^{192}Ir	0.67
^{226}Ra+	3.3
^{235}U+$^{\#}$	0.3
^{238}Pu+	-
^{239}Pu+	-
^{241}Am+	-

Notes:

* Radionuclides for which the ingrowth of daughter radionuclides following deposition of the parent radionuclide was considered are indicated with the ‘+’ sign.

[#] Maximum beta energies based on data taken from ICRP (1983). As ICRP (1983) only gives the average energy for each beta particle emission, the average energies have been multiplied by three to give approximate maximum energies, consistent with those in Delacroix (2002).

Figure A1 Range of beta particles in air as a function of beta energy

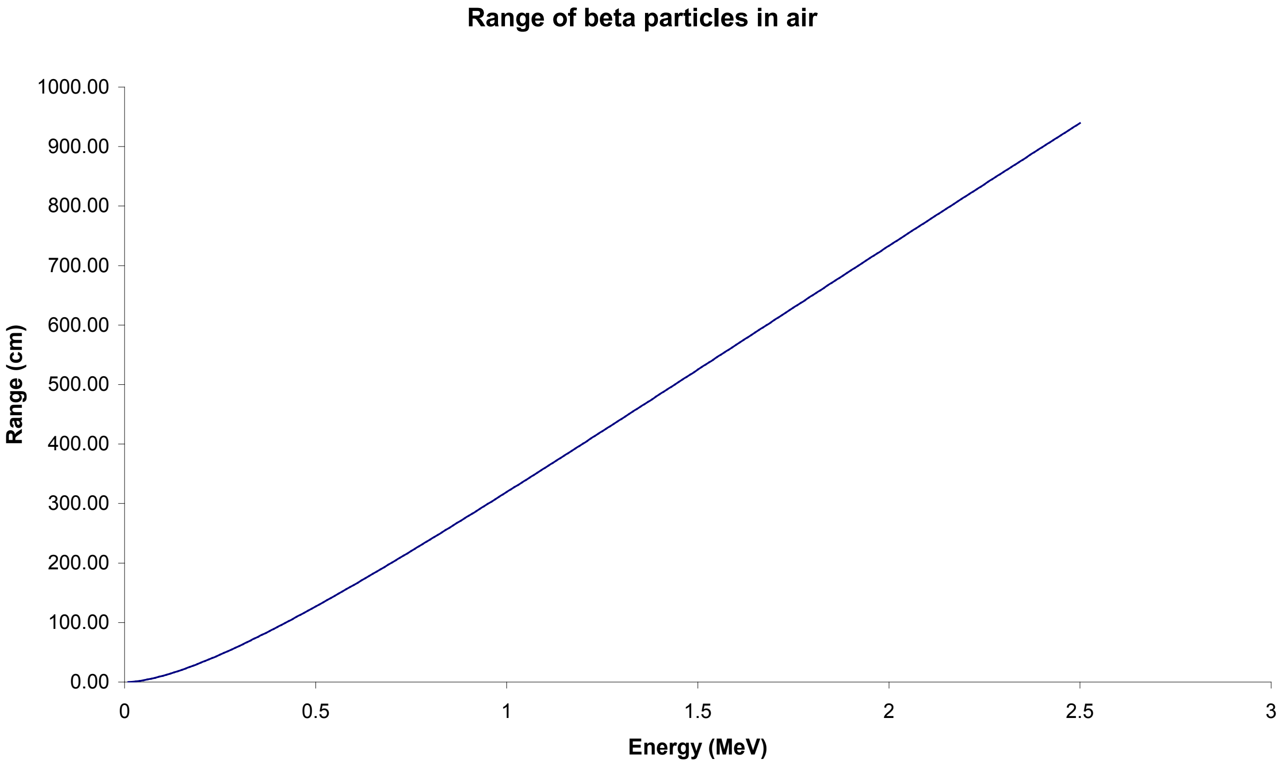


Figure A2 Nomogram for ascertaining thickness of material needed to reduce beta dose rates as a function of beta energy (taken from Longworth, 1988).

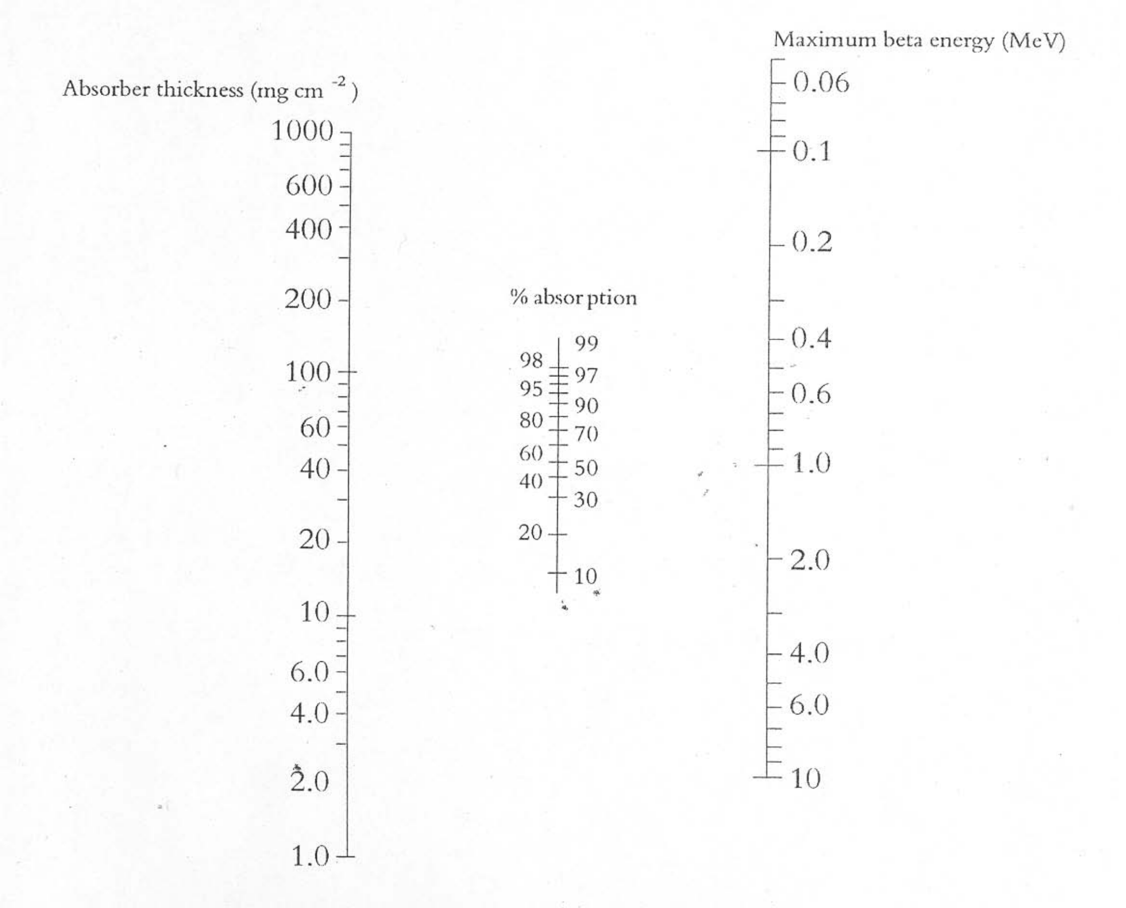
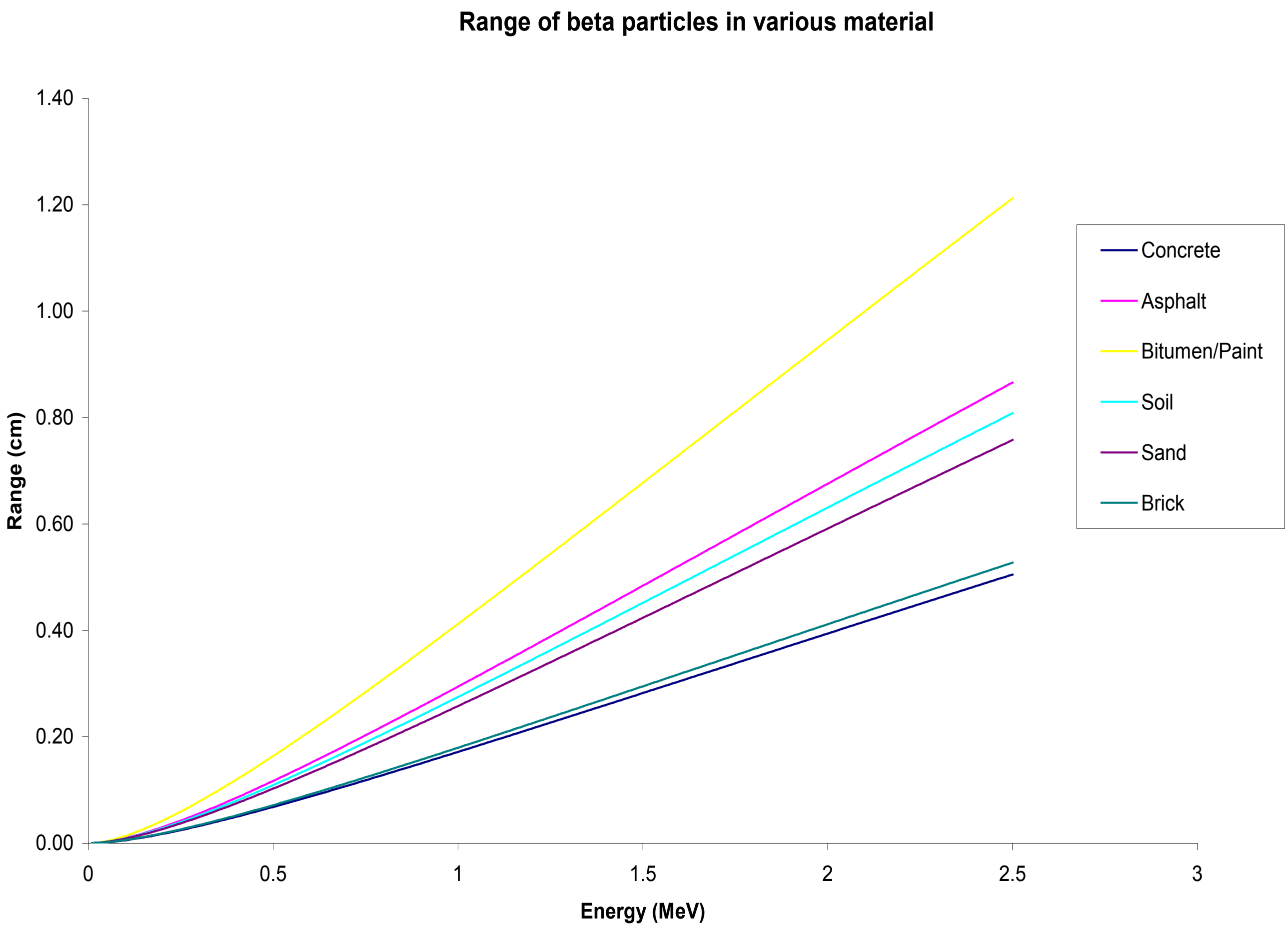


Figure A3 Range of beta particles in materials likely to be used for shielding in inhabited areas as a function of maximum beta energy



A4 GAMMA EMITTING RADIONUCLIDES

Gamma rays are attenuated by the material they pass through but they do not have a defined range.

The attenuation of a narrow beam of gamma or X-rays is given by:

$$I = I_0 \, e^{-\mu t}$$

where I is the fluence rate after passing through a thickness t (cm), I_0 is the initial fluence rate and μ is the linear attenuation coefficient of the attenuating medium (cm^{-1}). In the case of broad or uncollimated beams, build-up can occur due to scattered photons still reaching the target which causes the attenuation to be less rapid than indicated in the above equation.

Materials with high atomic number and high density, such as lead, provide the best shields for gamma and X-rays, although these are unlikely to be practicable for shielding within contaminated inhabited areas.

The greater the density of a material the smaller the thickness needed to decrease the gamma ray intensity to a specified extent. This means that the mass of materials needed to decrease the intensity of the radiation by a certain amount is very nearly the same irrespective of the material. Two quantities are normally used to specify the thickness: the half value thickness and the tenth value thickness which are the thicknesses of a material required to reduce the gamma ray intensity by a factor of two or by a factor of ten, expressed by:

$$\text{Half value thickness (cm)} = \frac{0.693}{\mu}$$

$$\text{Tenth value thickness (cm)} = \frac{2.3}{\mu}$$

Where μ is the linear attenuation coefficient in the shielding material for the gamma energy of concern (cm^{-1}).

Table A6 gives linear attenuation coefficients in air as a function of gamma energy. Linear attenuation coefficients for other materials can be estimated using the assumption that the linear attenuation coefficient is approximately proportional to the density of the material. This assumption holds for gamma energies in the range of about 0.05 – 5.0 MeV for most of the materials that are considered as shielding materials in Section A3. For materials, such as lead, that have a high atomic number, this approach would not be appropriate. However, linear attenuation coefficients are readily available for lead and are given in Table A7 for a range of gamma energies (Kaplan, 1979).

For other shielding materials of relevance for use in recovery options in inhabited areas, the linear attenuation coefficient for the material of interest can be estimated in the following way:

$$\mu_{material} = \mu_{air} \frac{\rho_{material}}{\rho_{air}}$$

where μ is the linear attenuation coefficient in material (cm^{-1}), μ_{air} is the linear attenuation coefficient in air (cm^{-1}) ρ_{material} is the density of material (kg m^{-3}) and ρ_{air} is the density of air (1.293 kg m^{-3}).

For example, if the radionuclide in the contamination has a gamma energy of 1MeV and the material to be used is soil (1500 kg m^{-3}) the linear attenuation coefficient for soil can be calculated to be

$$\mu_{soil} = 8.23 \cdot 10^{-5}\ \text{cm}^{-1}\ \frac{1500\ \text{kg m}^{-3}}{1.293\ \text{kg m}^{-3}} = 0.095\ \text{cm}^{-1}$$

Assuming a thickness of soil of 10 cm is used, the intensity of gamma irradiation with soil shielding is 0.39 I_0 where I_0 is the intensity of gamma irradiation with no shielding. This means that 10 cm of soil reduce the intensity of the gamma irradiation from the radionuclide to about 40% of that with no shielding in place.

The half value thickness for the radionuclide can be estimated to be about 7 cm of soil, i.e. a thickness of 7 cm reduces the intensity by a half. The tenth value thickness for the radionuclide can be estimated to be about 24 cm, i.e. a thickness of 24 cm reduces the intensity to a tenth.

Table A6 Linear attenuation coefficients for gamma rays in air

Gamma energy, (MeV)	Linear attenuation coefficient (cm^{-1}) *
0.1	$1.99\ 10^{-4}$
0.2	$1.60\ 10^{-4}$
0.3	$1.38\ 10^{-4}$
0.5	$1.13\ 10^{-4}$
0.6	$1.04\ 10^{-4}$
0.8	$9.15\ 10^{-5}$
1.0	$8.23\ 10^{-5}$
2.0	$5.75\ 10^{-5}$
3.0	$4.63\ 10^{-5}$
5.0	$3.56\ 10^{-5}$
10.0	$2.64\ 10^{-5}$

Note:

* The attenuation coefficients are calculated assuming that air consists of 78% nitrogen, 21% oxygen and 1% argon and has a density of 1.293 kg m^{-3}.

Table A7 Linear attenuation coefficients for lead

Gamma energy, (MeV)	Linear attenuation coefficient,(cm^{-1}) *
0.1	60
0.2	10
0.3	3.8
0.5	1.6
0.6	1.3
0.8	0.95
1.0	0.77
2.0	0.51
3.0	0.46
5.0	0.49
10.0	0.57

Note:

* Calculated assuming a density of lead of 1.134 10^4 kg m^{-3}

A5 REFERENCES

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APPENDIX B

Estimating doses in the affected area

Doses to people in inhabited areas can come from a variety of different exposure pathways. For a given amount of radioactive material deposited, the resultant dose to an individual can vary widely, depending on the radionuclides involved, the spread of contamination between different surfaces and the time spent by individuals in different locations relative to the contamination.

An individual living in a contaminated environment is exposed to a combination of dose rates arising from the differing levels of contamination on different surfaces and objects in a variety of locations (e.g. houses, work places, recreational areas). The dose rate at a single location also varies with time as radionuclides decay or are removed by rain and other weathering processes. The cumulative dose experienced by an individual is therefore determined by the time spent at each location and the dose rate at that location.

This section provides some guidance on robust methods to calculate of doses in an inhabited area from contamination levels on surfaces or from resuspension. It should be stressed that these methods are in general basic and only intended to give the user a general idea of the levels of dose that would be received. When selecting recovery management options, it is recommended that more detailed and complex models are used, such as the model implemented in ERMIN (Jones et al, 2009). Such a model can take account of the characteristics of each of the areas being considered (e.g. the types of building in the area, the level of urbanisation, the amount of the area used as gardens, parks) and the partitioning of contamination within this environment as a function of time. The following information is given in this appendix to aid the calculation of doses to members of the public in inhabited areas:

- indicative outdoor effective dose rates and doses from external irradiation from gamma emitting material deposited on the ground (see Section B1, Table B1 and Table B2);
- location and occupancy factors to estimate doses to people under normal living conditions (see Section B2 and Table B3)
- indicative effective dose rates and doses deposited on the ground for ^{90}Sr (see Section B3);
- outdoor inhalation doses from resuspended material per unit activity deposited on the ground as a function of time (see Section B4 and Table B4).

B1 EXTERNAL GAMMA DOSES FROM CONTAMINATION ON OUTDOOR SURFACES IN THE ENVIRONMENT

Table B1 and Table B2 provide dose rates and doses that would be expected over different periods in an inhabited area once levels of deposition on grass and underlying soil, away from buildings, are available. Generic soil with the density of 1.5 g cm^{-3} was assumed in the calculations, with a composition by mass of O 60%, Si 25%, C 7%, H 4%, Al 3% and Fe 1%. Table B1 provides dose rates in Sv h^{-1} per 1 Bq m^{-2} deposited on the ground from external gamma from radioactive material deposited outdoors to an individual outdoors for different times after the event. The dose rates are calculated 1 m above an infinite soil surface (or grass with underlying soil), taking into account the migration of radioactive contamination down through the soil with time. Table B2 provides doses per unit activity deposition on the ground from external gamma from radioactive material deposited outdoors to an individual outdoors for different times after the event. The values in the tables give conservative estimates of dose rates and doses for the following reasons.

- It is assumed that all the contamination is initially located on the surface of the soil. In reality, not all of the deposited material will remain on the surface; processes such as bioturbation and water washing contamination directly into the soil during rainfall provide some shielding from the contamination. Migration of contamination down through the soil in the longer term is taken into account.
- Doses from contamination on the ground come from limited areas since an inhabited area usually has many shielding elements (e.g. buildings). Andersson (1996) calculated that about one-third of the dose rate would, in a large open area, come from contamination that is more than 16 m away with about one-eighth of the dose rate coming from contamination more than 64 m away
- No account has been taken of the shielding provided by buildings for a person outside and this may lead to dose rates outdoors being overestimated. Reductions in dose rate relative to dose rates in a large open area have been estimated for a number of different types of inhabited area (e.g. with lots of trees and vegetation compared to a heavily urbanised area (Meckbach et al, 1988a; Brown and Jones, 1993). For most situations it is appropriate to assume that shielding from buildings does not reduce dose rates outdoors significantly and it can be ignored for scoping calculations of external doses. More complex models used to assess doses within specific areas can take into account any shielding provided by buildings.

Table B1 Effective external gamma dose rates after an instantaneous deposit of 1 Bq m^{-2} on the ground (HPA-PRD, 2005)

	Dose rate (Sv h^{-1})[a]											
Radionuclide	0	6 hours	12 hours	1 day	2 days	7 days	30 days	1 year	2 years	5 years	10 years	50 years
^{60}Co	$5.6\ 10^{-12}$	$5.6\ 10^{-12}$	$5.6\ 10^{-12}$	$5.6\ 10^{-12}$	$5.6\ 10^{-12}$	$5.6\ 10^{-12}$	$5.5\ 10^{-12}$	$4.4\ 10^{-12}$	$3.5\ 10^{-12}$	$1.8\ 10^{-12}$	$6.9\ 10^{-13}$	$9.9\ 10^{-16}$
^{75}Se	$8.9\ 10^{-13}$	$8.9\ 10^{-13}$	$8.9\ 10^{-13}$	$8.8\ 10^{-13}$	$8.8\ 10^{-13}$	$8.5\ 10^{-13}$	$7.4\ 10^{-13}$	$9.5\ 10^{-14}$	$1.0\ 10^{-14}$	$1.3\ 10^{-17}$	$7.4\ 10^{-22}$	$2.3\ 10^{-26}$
^{95}Zr[b]	$1.7\ 10^{-12}$	$1.7\ 10^{-12}$	$1.7\ 10^{-12}$	$1.7\ 10^{-12}$	$1.8\ 10^{-12}$	$1.8\ 10^{-12}$	$1.9\ 10^{-12}$	$9.4\ 10^{-14}$	$1.6\ 10^{-15}$	$4.6\ 10^{-20}$	$1.6\ 10^{-23}$	0
^{95}Nb	$1.8\ 10^{-12}$	$1.8\ 10^{-12}$	$1.8\ 10^{-12}$	$1.7\ 10^{-12}$	$1.7\ 10^{-12}$	$1.6\ 10^{-12}$	$9.7\ 10^{-13}$	$1.2\ 10^{-15}$	$8.7\ 10^{-19}$	$7.5\ 10^{-23}$	$1.3\ 10^{-26}$	0
^{99}Mo[b]	$3.5\ 10^{-13}$	$3.3\ 10^{-13}$	$3.1\ 10^{-13}$	$2.7\ 10^{-13}$	$2.1\ 10^{-13}$	$5.9\ 10^{-14}$	$1.8\ 10^{-16}$	0	0	0	0	0
^{103}Ru[b]	$1.1\ 10^{-12}$	$1.1\ 10^{-12}$	$1.1\ 10^{-12}$	$1.1\ 10^{-12}$	$1.1\ 10^{-12}$	$9.8\ 10^{-13}$	$6.5\ 10^{-13}$	$1.6\ 10^{-15}$	$2.3\ 10^{-18}$	$2.9\ 10^{-22}$	$6.6\ 10^{-26}$	0
^{106}Ru[b]	$4.8\ 10^{-13}$	$4.8\ 10^{-13}$	$4.8\ 10^{-13}$	$4.8\ 10^{-13}$	$4.8\ 10^{-13}$	$4.7\ 10^{-13}$	$4.5\ 10^{-13}$	$2.2\ 10^{-13}$	$9.7\ 10^{-14}$	$9.4\ 10^{-15}$	$2.2\ 10^{-16}$	$2.8\ 10^{-24}$
^{132}Te[b]	$5.0\ 10^{-13}$	$4.7\ 10^{-12}$	$5.2\ 10^{-12}$	$4.8\ 10^{-12}$	$3.9\ 10^{-12}$	$1.3\ 10^{-12}$	$9.9\ 10^{-15}$	0	0	0	0	0
^{131}I[b]	$8.9\ 10^{-13}$	$8.8\ 10^{-13}$	$8.6\ 10^{-13}$	$8.2\ 10^{-13}$	$7.5\ 10^{-13}$	$4.9\ 10^{-13}$	$6.7\ 10^{-14}$	$1.5\ 10^{-22}$	$1.1\ 10^{-25}$	0	0	0
^{134}Cs	$3.6\ 10^{-12}$	$3.6\ 10^{-12}$	$3.6\ 10^{-12}$	$3.6\ 10^{-12}$	$3.6\ 10^{-12}$	$3.6\ 10^{-12}$	$3.5\ 10^{-12}$	$2.3\ 10^{-12}$	$1.5\ 10^{-12}$	$4.1\ 10^{-13}$	$5.5\ 10^{-14}$	$2.3\ 10^{-20}$
^{136}Cs	$5.0\ 10^{-12}$	$4.9\ 10^{-12}$	$4.8\ 10^{-12}$	$4.7\ 10^{-12}$	$4.5\ 10^{-12}$	$3.4\ 10^{-12}$	$1.0\ 10^{-12}$	$1.1\ 10^{-19}$	$8.0\ 10^{-23}$	0	0	0
^{137}Cs[b]	$1.4\ 10^{-12}$	$1.4\ 10^{-12}$	$1.4\ 10^{-12}$	$1.4\ 10^{-12}$	$1.4\ 10^{-12}$	$1.4\ 10^{-12}$	$1.4\ 10^{-12}$	$1.2\ 10^{-12}$	$1.1\ 10^{-12}$	$7.5\ 10^{-13}$	$4.8\ 10^{-13}$	$4.4\ 10^{-14}$
^{140}Ba[b]	$4.2\ 10^{-13}$	$9.2\ 10^{-13}$	$1.4\ 10^{-12}$	$2.1\ 10^{-12}$	$3.1\ 10^{-12}$	$4.0\ 10^{-12}$	$1.2\ 10^{-12}$	$7.1\ 10^{-20}$	$5.3\ 10^{-23}$	0	0	0
^{144}Ce[b]	$1.1\ 10^{-13}$	$1.1\ 10^{-13}$	$1.1\ 10^{-13}$	$1.1\ 10^{-13}$	$1.1\ 10^{-13}$	$1.1\ 10^{-13}$	$1.00\ 10^{-13}$	$3.9\ 10^{-14}$	$1.4\ 10^{-14}$	$6.9\ 10^{-16}$	$5.3\ 10^{-18}$	$1.9\ 10^{-25}$
^{169}Yb	$6.0\ 10^{-13}$	$6.0\ 10^{-13}$	$6.0\ 10^{-13}$	$5.9\ 10^{-13}$	$5.8\ 10^{-13}$	$5.2\ 10^{-13}$	$3.1\ 10^{-13}$	$1.9\ 10^{-16}$	$7.8\ 10^{-20}$	$1.1\ 10^{-22}$	$1.5\ 10^{-26}$	0
^{192}Ir	$1.9\ 10^{-12}$	$1.9\ 10^{-12}$	$1.9\ 10^{-12}$	$1.9\ 10^{-12}$	$1.9\ 10^{-12}$	$1.8\ 10^{-12}$	$1.4\ 10^{-12}$	$5.6\ 10^{-14}$	$1.7\ 10^{-15}$	$6.3\ 10^{-20}$	$2.2\ 10^{-23}$	0
^{226}Ra[b]	$1.5\ 10^{-14}$	$1.7\ 10^{-13}$	$3.3\ 10^{-13}$	$6.4\ 10^{-13}$	$1.2\ 10^{-12}$	$2.8\ 10^{-12}$	$3.9\ 10^{-12}$	$3.5\ 10^{-12}$	$3.2\ 10^{-12}$	$2.4\ 10^{-12}$	$1.8\ 10^{-12}$	$4.6\ 10^{-13}$
^{235}U[b]	$3.4\ 10^{-13}$	$3.5\ 10^{-13}$	$3.5\ 10^{-13}$	$3.5\ 10^{-13}$	$3.6\ 10^{-13}$	$3.6\ 10^{-13}$	$3.6\ 10^{-13}$	$3.2\ 10^{-13}$	$2.8\ 10^{-13}$	$2.1\ 10^{-13}$	$1.4\ 10^{-13}$	$2.4\ 10^{-14}$
^{238}Pu	$2.1\ 10^{-16}$	$2.1\ 10^{-16}$	$2.1\ 10^{-16}$	$2.1\ 10^{-16}$	$2.1\ 10^{-16}$	$2.1\ 10^{-16}$	$2.1\ 10^{-16}$	$1.7\ 10^{-16}$	$1.3\ 10^{-16}$	$6.7\ 10^{-17}$	$2.4\ 10^{-17}$	$7.2\ 10^{-19}$
^{239}Pu	$1.8\ 10^{-16}$	$1.8\ 10^{-16}$	$1.8\ 10^{-16}$	$1.8\ 10^{-16}$	$1.8\ 10^{-16}$	$1.8\ 10^{-16}$	$1.7\ 10^{-16}$	$1.5\ 10^{-16}$	$1.2\ 10^{-16}$	$8.0\ 10^{-17}$	$4.6\ 10^{-17}$	$7.2\ 10^{-18}$
^{241}Am	$3.7\ 10^{-14}$	$3.7\ 10^{-14}$	$3.7\ 10^{-14}$	$3.7\ 10^{-14}$	$3.7\ 10^{-14}$	$3.6\ 10^{-14}$	$3.6\ 10^{-14}$	$3.1\ 10^{-14}$	$3.0\ 10^{-14}$	$1.7\ 10^{-14}$	$9.3\ 10^{-15}$	$8.9\ 10^{-16}$

a) Generic soil of 1.5 g cm^{-3} assumed in calculation, with composition by weight O 0.6, Si 0.25, C 0.07, H 0.04, Al 0.03 Fe 0.01.

b) The doses from the ingrowth of daughter radionuclides are included with the parent, i.e. ^{95}Zr includes ^{95m}Nb, ^{95}Nb; ^{99}Mo includes ^{99m}Tc, ^{99}Tc; ^{103}Ru includes ^{103m}Rh; ^{106}Ru includes ^{106}Rh; ^{132}Te includes ^{132}I; ^{131}I includes ^{131m}Xe; ^{135}I includes ^{135m}Xe, ^{135}Xe; ^{137}Cs includes ^{137m}Ba; ^{140}Ba includes ^{140}La; ^{144}Ce includes ^{144}Pr; ^{226}Ra includes ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Pb, ^{210}Bi, ^{210}Po; ^{235}U includes ^{231}Th.

Table B2 Integrated effective external gamma dose after an instantaneous deposit of 1 Bq m^{-2} on the ground (HPA-RPD, 2005)

	Dose (Sv)[a]										
Radionuclide	0	6 hours	12 hours	1 day	2 days	7 days	30 days	1 year	2 years	5 years	10 years	50 years
^{60}Co	0	$3.4\ 10^{-11}$	$6.8\ 10^{-11}$	$1.4\ 10^{-10}$	$2.7\ 10^{-10}$	$9.5\ 10^{-10}$	$4.0\ 10^{-9}$	$4.4\ 10^{-8}$	$7.8\ 10^{-8}$	$1.5\ 10^{-7}$	$2.0\ 10^{-7}$	$2.3\ 10^{-7}$
^{75}Se	0	$5.3\ 10^{-12}$	$1.1\ 10^{-11}$	$2.1\ 10^{-11}$	$4.2\ 10^{-11}$	$1.5\ 10^{-10}$	$5.8\ 10^{-10}$	$3.1\ 10^{-9}$	$4.4\ 10^{-9}$	$3.5\ 10^{-9}$	$3.5\ 10^{-9}$	$3.5\ 10^{-9}$
^{95}Zr[b]	0	$1.0\ 10^{-11}$	$2.1\ 10^{-11}$	$4.1\ 10^{-11}$	$8.3\ 10^{-11}$	$3.0\ 10^{-10}$	$1.3\ 10^{-9}$	$7.3\ 10^{-9}$	$7.5\ 10^{-9}$	$7.5\ 10^{-9}$	$7.5\ 10^{-9}$	$7.5\ 10^{-9}$
^{95}Nb	0	$1.1\ 10^{-11}$	$2.1\ 10^{-11}$	$4.2\ 10^{-11}$	$8.4\ 10^{-11}$	$2.8\ 10^{-10}$	$9.6\ 10^{-10}$	$2.1\ 10^{-9}$	$2.1\ 10^{-9}$	$2.1\ 10^{-9}$	$2.1\ 10^{-9}$	$2.1\ 10^{-9}$
^{99}Mo[b]	0	$2.0\ 10^{-12}$	$3.9\ 10^{-12}$	$7.3\ 10^{-12}$	$1.3\ 10^{-11}$	$2.7\ 10^{-11}$	$3.3\ 10^{-11}$	$3.3\ 10^{-11}$	$3.3\ 10^{-11}$	$3.3\ 10^{-11}$	$3.3\ 10^{-11}$	$3.3\ 10^{-11}$
^{103}Ru[b]	0	$6.7\ 10^{-12}$	$1.3\ 10^{-11}$	$2.7\ 10^{-11}$	$5.3\ 10^{-11}$	$1.8\ 10^{-10}$	$6.2\ 10^{-10}$	$1.5\ 10^{-9}$	$1.5\ 10^{-9}$	$1.5\ 10^{-9}$	$1.5\ 10^{-9}$	$1.5\ 10^{-9}$
^{106}Ru[b]	0	$2.9\ 10^{-12}$	$5.8\ 10^{-12}$	$1.2\ 10^{-11}$	$2.3\ 10^{-11}$	$8.0\ 10^{-11}$	$3.4\ 10^{-10}$	$2.9\ 10^{-9}$	$4.2\ 10^{-9}$	$5.2\ 10^{-9}$	$5.3\ 10^{-9}$	$5.3\ 10^{-9}$
^{132}Te[b]	0	$1.9\ 10^{-11}$	$5.0\ 10^{-11}$	$1.1\ 10^{-10}$	$2.1\ 10^{-10}$	$5.0\ 10^{-10}$	$6.5\ 10^{-10}$	$6.\ 10^{-10}$	$6.5\ 10^{-10}$	$6.5\ 10^{-10}$	$6.5\ 10^{-10}$	$6.5\ 10^{-10}$
^{131}I[b]	0	$5.3\ 10^{-12}$	$1.1\ 10^{-11}$	$2.1\ 10^{-11}$	$3.9\ 10^{-11}$	$1.1\ 10^{-10}$	$2.3\ 10^{-10}$	$2.5\ 10^{-10}$	$2.5\ 10^{-10}$	$2.5\ 10^{-10}$	$2.5\ 10^{-10}$	$2.5\ 10^{-10}$
^{134}Cs	0	$2.2\ 10^{-11}$	$4.3\ 10^{-11}$	$8.7\ 10^{-11}$	$1.7\ 10^{-10}$	$6.1\ 10^{-10}$	$2.6\ 10^{-9}$	$2.6\ 10^{-8}$	$4.2\ 10^{-8}$	$6.4\ 10^{-8}$	$7.1\ 10^{-8}$	$7.2\ 10^{-8}$
^{136}Cs	0	$2.9\ 10^{-11}$	$5.9\ 10^{-11}$	$1.2\ 10^{-10}$	$2.3\ 10^{-10}$	$7.0\ 10^{-10}$	$1.8\ 10^{-9}$	$2.2\ 10^{-9}$	$2.2\ 10^{-9}$	$2.2\ 10^{-9}$	$2.2\ 10^{-9}$	$2.2\ 10^{-9}$
^{137}Cs[b]	0	$8.4\ 10^{-12}$	$1.7\ 10^{-11}$	$3.3\ 10^{-11}$	$6.7\ 10^{-11}$	$2.3\ 10^{-10}$	$9.9\ 10^{-10}$	$1.1\ 10^{-8}$	$2.1\ 10^{-8}$	$4.5\ 10^{-8}$	$7.1\ 10^{-8}$	$1.3\ 10^{-7}$
^{140}Ba[b]	0	$4.1\ 10^{-12}$	$1.1\ 10^{-11}$	$3.2\ 10^{-11}$	$9.5\ 10^{-11}$	$5.6\ 10^{-10}$	$1.9\ 10^{-9}$	$2.5\ 10^{-9}$	$2.5\ 10^{-9}$	$2.5\ 10^{-9}$	$2.5\ 10^{-9}$	$2.5\ 10^{-9}$
^{144}Ce[b]	0	$6.5\ 10^{-13}$	$1.3\ 10^{-12}$	$2.6\ 10^{-12}$	$5.2\ 10^{-12}$	$1.8\ 10^{-11}$	$7.5\ 10^{-11}$	$6.0\ 10^{-10}$	$8.1\ 10^{-10}$	$9.2\ 10^{-10}$	$9.3\ 10^{-10}$	$9.3\ 10^{-10}$
^{169}Yb	0	$3.6\ 10^{-12}$	$7.2\ 10^{-12}$	$1.4\ 10^{-11}$	$2.8\ 10^{-11}$	$9.4\ 10^{-11}$	$3.2\ 10^{-10}$	$6.6\ 10^{-10}$	$6.6\ 10^{-10}$	$6.6\ 10^{-10}$	$6.6\ 10^{-10}$	$6.6\ 10^{-10}$
^{192}Ir	0	$1.2\ 10^{-11}$	$2.3\ 10^{-11}$	$4.6\ 10^{-11}$	$9.2\ 10^{-11}$	$3.1\ 10^{-10}$	$1.2\ 10^{-9}$	$4.6\ 10^{-9}$	$4.8\ 10^{-9}$	$4.8\ 10^{-9}$	$4.8\ 10^{-9}$	$4.8\ 10^{-9}$
^{226}Ra[b]	0	$5.1\ 10^{-13}$	$2.0\ 10^{-12}$	$7.8\ 10^{-12}$	$3.0\ 10^{-11}$	$2.8\ 10^{-10}$	$2.3\ 10^{-9}$	$3.2\ 10^{-8}$	$6.1\ 10^{-8}$	$1.3\ 10^{-7}$	$2.2\ 10^{-7}$	$5.4\ 10^{-7}$
^{235}U[b]	0	$2.1\ 10^{-12}$	$4.1\ 10^{-12}$	$8.3\ 10^{-12}$	$1.7\ 10^{-11}$	$6.0\ 10^{-11}$	$2.6\ 10^{-10}$	$3.0\ 10^{-9}$	$5.6\ 10^{-9}$	$1.2\ 10^{-8}$	$1.9\ 10^{-8}$	$4.1\ 10^{-8}$
^{238}Pu	0	$1.3\ 10^{-15}$	$2.6\ 10^{-15}$	$5.1\ 10^{-15}$	$1.0\ 10^{-14}$	$3.6\ 10^{-14}$	$1.5\ 10^{-13}$	$1.7\ 10^{-12}$	$3.0\ 10^{-12}$	$5.5\ 10^{-12}$	$7.3\ 10^{-12}$	$8.8\ 10^{-12}$
^{239}Pu	0	$1.1\ 10^{-15}$	$2.1\ 10^{-15}$	$4.2\ 10^{-15}$	$8.4\ 10^{-15}$	$2.9\ 10^{-14}$	$1.3\ 10^{-13}$	$1.4\ 10^{-12}$	$2.6\ 10^{-12}$	$5.2\ 10^{-12}$	$7.8\ 10^{-12}$	$1.4\ 10^{-11}$
^{241}Am	0	$2.2\ 10^{-13}$	$4.4\ 10^{-13}$	$8.8\ 10^{-13}$	$1.8\ 10^{-12}$	$6.1\ 10^{-12}$	$2.6\ 10^{-11}$	$2.9\ 10^{-10}$	$5.4\ 10^{-10}$	$1.1\ 10^{-9}$	$1.6\ 10^{-9}$	$2.7\ 10^{-9}$

a) Generic soil of 1.5 g cm^{-3} assumed in calculation, with composition by weight O 0.6, Si 0.25, C 0.07, H 0.04, Al 0.03 Fe 0.01.

b) The doses from the ingrowth of daughter radionuclides are included with the parent, i.e. ^{95}Zr includes ^{95m}Nb, ^{95}Nb; ^{99}Mo includes ^{99m}Tc, ^{99}Tc; ^{103}Ru includes ^{103m}Rh; ^{106}Ru includes ^{106}Rh; ^{132}Te includes ^{132}I; ^{131}I includes ^{131m}Xe; ^{135}I includes ^{135m}Xe, ^{135}Xe; ^{137}Cs includes ^{137m}Ba; ^{140}Ba includes ^{140}La; ^{144}Ce includes ^{144}Pr; ^{226}Ra includes ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Pb, ^{210}Bi, ^{210}Po; ^{235}U includes ^{231}Th.

B2 LOCATION AND OCCUPANCY FACTORS TO ESTIMATE DOSES TO PEOPLE INDOORS FROM DEPOSITION OUTDOORS

People typically tend to stay indoors for about 80% to 95% of the time (Jenkins et al, 1992; Andersson, 1996; Long et al, 2001; Kousa et al, 2002). During this time, they are shielded against radiation from outdoor contamination. The extent of this shielding depends on the characteristics of the specific buildings. The values in Table B1 and Table B2 therefore need to be modified using a location factor, which takes into account the shielding provided by the building in question.

Table B3 shows typical location factors for areas with buildings with different characteristics, ranging from thin wooden walls to thick brick and concrete walls (Andersson, 2005). The location factors are given for ^{137}Cs (representative of medium-high energy gamma emitters) shortly after deposition. These location factors can be used as default values for all the radionuclides considered in the Handbook. It should be noted, however, that the shielding offered by medium and high shielding buildings could be about twice as large for gamma-emitting radionuclides with energies around 300 keV compared to those with energies around 3 MeV (Meckbach et al, 1988b). The location factor changes with time, since the natural removal and migration processes of contamination on different surfaces are different. However, for areas with relatively large unpaved ground areas, such as a garden, changes to the location factors over a period of 10 years are expected to be limited (within about 50 %) and can be ignored for the purposes of estimating doses. For urban centres with little or no unpaved ground, long-term doses estimated using time-invariable location factors in Table B3 are likely to be conservative. The presence of airborne contaminants inside buildings leads to deposition on interior surfaces of the building. These deposits will give rise to a dose contribution to persons staying in the buildings. The location factors given in Table B3 take into account that some of the dose received come from contamination that was deposited indoors and that this dose is not affected substantially by the shielding offered by building walls.

Table B3 Location factors for ^{137}Cs (662 keV) for buildings with different shielding properties

Area type	Location factor estimate
Low shielding building	0.62
Medium shielding building	0.14
High shielding building	0.03

Using the values given in Table B2 and Table B3, a simple estimate of external gamma dose from material deposited outdoors can be made using the :

$$\mathrm{D}_{\mathrm{ext.,\,gamma}} = Dep \times Ext_{outdoors}\left(F_{outdoors} + LF \times F_{indoors}\right)$$

where $D_{\text{ext, gamma}}$ is the external gamma dose (Sv), Dep is the deposition on ground (Bq m^{-2}) $\text{Ext}_{\text{outdoors}}$ is the external gamma dose outdoors per unit deposition (Sv m^{2} Bq^{-1}), F_{outdoors} and F_{indoors} are the fractions of time spent outdoors and indoors respectively and LF is the location factor.

B3 EXTERNAL BETA DOSES FROM CONTAMINATION ON OUTDOOR OR INDOOR SURFACES

Beta particles have a short range in any material, including air. Therefore beta radiation from contaminated surfaces in the environment is only likely to be significant if the distance between the exposed person and the source is of a few metres at most, the energy of the emitted beta particles is high and there is virtually no shielding material between the person and the source: even thin cotton clothing protects well against most types of beta radiation (ICRU, 1997). A highly conservative estimate of the dose rate to skin from the high energy beta particles emitted from a uniform ^{90}Sr contamination on a ground surface would be of the order of 4 10^{-11} Sv h^{-1} per Bq^{-1} m^2 (Eckerman and Ryman, 1993). The effective dose would typically be about 2 orders of magnitude lower (4 10^{-13} Sv h^{-1} per Bq^{-1} m^2). Doses from external exposures to beta radiation are likely to be of low significance, particularly if radionuclides emitting gamma rays are also present. The estimates given above are based on contamination lying on the surface of the ground. The shielding effect of soil is so great that the dose rate to the skin would be about 3 orders of magnitude lower if the contamination was 1 cm under the surface, as it would be expected to be shortly after an airborne contamination, particularly if it occurred in rain. Contamination on impermeable surfaces, such as asphalted playgrounds may, however, give rise to doses from external exposure to beta radiation over longer periods of time as contamination does not penetrate into the surface and natural weathering is relatively slower. However, most of the contamination on these types of asphalt surfaces is typically gone within a year (Andersson, 2005).

Migration of contaminants into indoor surfaces is likely to be less significant than on outdoor surfaces. People may be in close contact with the radioactivity when they are sitting or lying on contaminated surfaces. In such cases, doses from beta radiation can be compared with those from the same activity deposited on skin/clothing on the body. As even thin fabric offers some protection against beta radiation, the most critical situations would be those where unshielded skin comes into direct contact with a contaminated surface; for example if a pillowcase is contaminated, the face may be in direct contact with the surface for a number of hours. If ordinary machine washing of pillowcases is efficient in removing the contaminants, these doses are likely to be limited to a short period of time after the contamination took place (Andersson et al, 2002). However, based on current knowledge, it cannot be ruled out that bedding and frequent use of chairs or sofas, if contaminated, may result in significant doses from external exposure to beta radiation or internal exposure from inhalation of resuspended material.

B4 DOSES FROM INHALATION OF RESUSPENDED CONTAMINANTS

Resuspension of contaminated particles may lead to further inhalation doses after deposition has occurred. Nevertheless, doses from inhalation of resuspended matter would in many cases be very low compared with doses from external exposure to beta particles and gamma rays and also lower than those received during the passage of the initial contaminating plume (Andersson et al, 2004). However, for radionuclides that are only alpha emitters, or predominantly alpha emitters, this could be the only significant exposure route during the recovery phase. Doses from inhalation of resuspended contaminants greatly depend on the processes leading to the resuspension and are influenced by factors such as dust concentrations on surfaces, dust particle sizes, mechanical disturbances (e.g. heavy traffic) and weather conditions. Resuspension factors (the ratios of aerosol concentration in air at a reference height above a surface to the aerosol particle loading per unit area of the surface) have been reported to vary by many orders of magnitude for particles deposited in inhabited areas (Sehmel, 1980). Due to the complexity of the calculations involved, inhalation doses from resuspension should be evaluated by experts, taking into account the relevant factors on a site specific basis. Indicative estimates of outdoor inhalation doses from resuspension have been reported (Walsh, 2002) and are given in Table B4. Doses are given per unit activity deposition on the ground; they were calculated assuming lung absorption type S (ICRP, 1995) and an inhalation rate of 2.3 10^{-4} m^3 s^{-1}. It is recommended that the values be used with caution and only where more exact models are not available.

Andersson et al (2004) demonstrated that even the most vigorous physical activity leads to only low levels of resuspended contaminants indoors. The resulting redistribution of contaminants on the various indoor surfaces does not contribute significantly to the dose from external exposure. Some cleaning techniques such as vacuum cleaning with machines with poor dust filters and shaking of cushions and other fabrics may give rise to higher levels of resuspended contaminants indoors and some redistribution of contamination within buildings.

Table B4 Adult committed effective dose from inhalation of resuspended contaminated material from the ground (Sv m^2 Bq^{-1})

	Inhalation period after deposition							
Radionuclide	1 day	3 days	1 week	1 month	6 months	1 year	4 years	10 years
^{106}Ru	$1.6\ 10^{-12}$	$3.3\ 10^{-12}$	$4.6\ 10^{-12}$	$6.9\ 10^{-12}$	$9.3\ 10^{-12}$	$9.9\ 10^{-12}$	$1.1\ 10^{-11}$	$1.1\ 10^{-11}$
^{103}Ru	$7.2\ 10^{-14}$	$1.5\ 10^{-13}$	$2.0\ 10^{-13}$	$2.8\ 10^{-13}$	$3.2\ 10^{-13}$	$3.2\ 10^{-13}$	$3.2\ 10^{-13}$	$3.2\ 10^{-13}$
^{137}Cs	$9.3\ 10^{-13}$	$2.0\ 10^{-12}$	$2.7\ 10^{-12}$	$4.1\ 10^{-12}$	$5.8\ 10^{-12}$	$6.4\ 10^{-12}$	$7.6\ 10^{-12}$	$8.4\ 10^{-12}$
^{226}Ra	$2.3\ 10^{-10}$	$4.8\ 10^{-10}$	$6.7\ 10^{-10}$	$1.0\ 10^{-9}$	$1.4\ 10^{-9}$	$1.6\ 10^{-9}$	$1.9\ 10^{-9}$	$2.1\ 10^{-9}$
^{235}U	$2.0\ 10^{-10}$	$4.3\ 10^{-10}$	$6.0\ 10^{-10}$	$9.0\ 10^{-10}$	$1.3\ 10^{-9}$	$1.4\ 10^{-9}$	$1.7\ 10^{-9}$	$1.9\ 10^{-9}$
^{238}Pu	$3.8\ 10^{-10}$	$8.0\ 10^{-10}$	$1.1\ 10^{-9}$	$1.7\ 10^{-9}$	$2.4\ 10^{-9}$	$2.6\ 10^{-9}$	$3.2\ 10^{-9}$	$3.5\ 10^{-9}$
^{239}Pu	$3.8\ 10^{-10}$	$8.0\ 10^{-10}$	$1.1\ 10^{-9}$	$1.7\ 10^{-9}$	$2.4\ 10^{-9}$	$2.6\ 10^{-9}$	$3.2\ 10^{-9}$	$3.5\ 10^{-9}$
^{241}Am	$3.8\ 10^{-10}$	$8.0\ 10^{-10}$	$1.1\ 10^{-9}$	$1.7\ 10^{-9}$	$2.4\ 10^{-9}$	$2.6\ 10^{-9}$	$3.2\ 10^{-9}$	$3.5\ 10^{-9}$

B5 OTHER POTENTIAL EXPOSURE PATHWAYS

B5.1 Bremsstrahlung doses

All beta contamination on a surface gives rise to small quantities of bremsstrahlung radiation. Bremsstrahlung emissions are photons produced by beta particles interacting with surrounding matter which are more penetrating than beta particles in the body. These also contribute to effective dose. The dose from bremsstrahlung radiation from material on a surface is generally small compared to the effective dose from beta emissions. However, for very high levels of beta contamination, doses from bremsstrahlung radiation may need to be included in the estimated doses while planning a recovery strategy.

If the beta radiation is stopped by a shielding material, bremsstrahlung radiation is still created. The shielding material used on top of the beta contamination increases the intensity of the bremsstrahlung radiation and the increase is dependent on the shielding material used. The increase in dose from bremsstrahlung radiation for materials likely to be used for shielding in inhabited areas such as tarmac and soil, is small compared to the dose from beta radiation. If lead is used as a shielding material for small areas of contamination in special situations, more bremsstrahlung radiation is created and therefore an assessment of the bremsstrahlung doses that could be expected should be made, particularly for high energy beta emitters such as ^{90}Sr and its daughter ^{90}Y.

If both beta and gamma emitters are present, any increase in dose from bremsstrahlung radiation is likely to be small compared to the dose from external exposure to gamma emitters. In this case, bremsstrahlung radiation is only an issue if beta radiation is stopped by shielding. However, this is not expected to be of concern as shielding is very unlikely to be used against gamma emitters.

B5.2 Doses from ‘hot particles’

‘Hot particles’ are small highly radioactive particles which may be deposited in the environment if an explosion occurs, e.g. after a Radiological Dispersion Device (RDD), also called a ‘dirty bomb’. These particles are likely to be too big to cause any significant exposure via inhalation, although it is possible that they may deposit in the nose. The most important exposure pathways for hot particles are, in general, ingestion and skin contamination. Contamination of skin can give rise to very high local skin doses from both beta and gamma emitters. Small, hot particles produce spatially non-uniform acute doses to small areas of the skin and can produce erythema, ulceration and in the most severe cases moist desquamation (NRPB, 1996, Wilkins et al, 1998). Delacroix et al (2002) indicates that dose rates of up to 4 mSv h^{-1} per kBq cm^{-2} on the skin for high energy emitters could be expected for uniform contamination of the skin and 2 mSv h^{-1} expected for a droplet of 1 kBq on the skin.

Deterministic effects to the lower large intestine may result from the ingestion of hot particles. The passage of a fuel fragment through the gastrointestinal (GI) tract will be different to normal radionuclides ingested as a dissolved fraction in food. Fragments may become lodged in the parts of the GI tract and as a result the normal residence time in particular organs may be increased. Additional information on deterministic effects is presented by Charles and Harrison (2007).

B6 RELATIVE IMPORTANCE OF DIFFERENT SURFACES IN CONTRIBUTING TO EXTERNAL DOSES

Many outdoor surfaces in an inhabited area would become contaminated following deposition of airborne contaminants. The distribution of the contaminants on the different surfaces depends on whether the deposition occurred in dry weather or while it was raining. The Chernobyl accident showed that the deposition of small condensation particles in the 1 µm range, carrying radiocaesium, generally followed two characteristic patterns, depending on whether the weather was dry or the deposition occurred while it was raining. Table B5 shows the expected contamination levels on different surfaces of such particles, shortly after the accident, relative to that on a surface with grass and underlying soil (a cut lawn) for both wet and dry deposition (Roed, 1990). Different figures could be expected for other particle sizes, such as those originating from other types of radiological emergencies. It should be noted that the ratios given in Table B5 apply to deposition from a plume dispersing from a source well outside the inhabited area under consideration. The figures for trees/shrubs are per unit of area covered by the vegetation. The relative deposition for trees/shrubs in leaf is particularly high for dry deposition, as the leaves filter the contamination very effectively. The use of these values is only recommended to obtain an approximate estimate of contamination levels on different surfaces in situations where actual measurements on the different surfaces are not available. The actual relative deposition to surfaces from a source within the inhabited area depends on a number of factors, such as the type and size of the particles and the distance from the point of release.

Table B5 Typical contamination levels of 1 µm particles measured on different surfaces after the Chernobyl accident

Surfaces	Relative dry deposition	Relative wet deposition
Walls	0.1	0.01
Roofs	1.0	0.4
Cut lawn	1.0	1.0
Roads	0.4	0.5
Trees and shrubs	3.0	0.1

After deposition, the contamination on roads, external house walls and roof will be depleted by wind and weather (Roed, 1990). The Chernobyl accident provided much information on the natural removal of radiocaesium on such surfaces. As caesium can bind particularly strongly to the surface of most common construction materials, use of this information to describe the behaviour of other radionuclides will lead to cautious dose estimates.

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APPENDIX C

Management of contaminated waste from clean up

C1 PROCESSES TO TREAT OR MINIMISE THE VOLUME OF CONTAMINATED WASTE

The management of contaminated waste may include a number of the treatment processes prior to final storage or disposal of the waste. In addition, if, for example, the dose rate is dominated by contributions from short-lived radionuclides or if the waste requires the use of various treatment processes prior to final disposal it may be beneficial to store contaminated waste in a temporary repository for a period of time.

C1.1 Filtration of solid particles out of waste water

A number of management options involve the use of water to wash off particles consisting of other materials (e.g. algae and moss, roof materials). These particles normally retain the contamination well (particularly caesium) and can be collected along with the wash-water. Simple filtration through an inexpensive polymer fibre textile with a pore size of 0.14 mm has been found to be highly effective in isolating the solid particles, which contained virtually all caesium contamination, from the water in areas contaminated by the Chernobyl accident (Fogh et al, 1999). The water could then be safely disposed of via sewers or even re-applied on the roof.

C1.2 Treatments for contaminants in liquid waste

Some management options involve the use of detergent solutions. Some of these detergents will be diluted and non-aggressive, whereas others may be highly acidic or alkaline. The acidity of the solution determines to a great extent the degree of contaminant association with particles.

Several methods may be applicable to remove contaminant ions from the waste solution, if required prior to disposal. One of the more simple methods is to concentrate the contamination in a solid residue using evaporation. This technique requires very large amounts of energy (> 1000 kWh m^{-3}) (Turner et al, 1994) and may not be easy to handle with strong, reactive solutions. Furthermore, the presence of volatile contaminants, such as ruthenium, would be problematic.

An alternative method is to precipitate the contaminants by adding a flocculant agent and adjusting the solution pH to neutral. However, the neutralisation process would lead to the generation of large amounts of precipitate (IAEA, 1993). Also, the typical decontaminating effect of gravitational settling by neutralisation has been reported to be limited (maximum DF of about 10) (Turner et al, 1994). In connection with both evaporation and precipitation, very large, specialised handling facilities would be required.

A further, potentially attractive, alternative method is to remove the contaminants from the solution by ion exchange (IX). This has been reported to be a highly efficient technique. In addition, the required size of the handling facility would be much less than that of an evaporation or gravity settling plant (Turner et al, 1994).

For treatment of relatively large amounts of contaminated liquid, membrane filters based on the reverse osmosis principle may be highly attractive. Membrane filters are reported to be highly efficient in reducing the concentrations of radionuclides in liquid waste (DF of several hundreds per cycle) (Zakrzewska-Trznadel et al, 2001).

Liquid radioactive waste could be diluted to give sufficiently low activity concentrations in the waste that it can be disposed of as ordinary waste liquid. Stirring systems for certification of the homogeneity of solutions of radioactive liquid waste have been developed for this purpose (Ogata and Nishizawa, 1999). However, dilution must be sufficiently effective with respect to toxicity, acidity and radionuclide content.

C1.3 Stabilisation of solid waste to avoid migration of contaminants

Some types of collected solid waste arising from the implementation of a management option (e.g. street dust, ash from combustion of contaminated biomass) can contain particularly high concentrations of radionuclides. In constructing ground repositories for strongly contaminated solid waste it may be appropriate to introduce special measures to prevent migration of contaminants to the groundwater. Thick plastic lining or other membranes around the contaminated material will generally provide good protection together with clay barriers and draining layers of gravel, and would be recommended for any ground repository for solid waste.

To stabilise further waste from highly contaminated surfaces, cementation could be considered, particularly if the contaminants would otherwise have high environmental mobility. For instance, fly-ash from combustion would be a 'natural' ingredient in a cement mixture. However, conventional cementation processes is not possible for all materials because the presence of some materials (e.g. humic materials) retards or prevents solidification.

C2 WASTE MANAGEMENT OPTIONS FOR SOLID WASTE ARISING FROM CLEAN-UP

Waste disposal schemes for solid contaminated waste must be selected with care. To cope with a radiological emergency, the identification of waste management options, including the construction of repositories and storage facilities, is required fairly quickly. Waste management options should therefore be planned for and the required materials, transport vehicles, skilled workers, infrastructure, etc. should be put in place to manage the waste appropriately. If permanent disposal options are required, engineered facilities could not realistically be constructed on the timescales needed. Therefore, temporary or indefinite storage options for the waste are also important. A checklist for setting up facility for temporary storage can be found in Table C1.

Table C1 Checklist for temporary storage

Potential Issue	Consider
Water infiltration	Need to store waste in watertight drums or containers inside a building.
Containment	Do containers need to be chemically and radiologically stable? Provide shielding? Be mechanically robust (impact, thermal)? Be portable?
Leachate and atmospheric emissions	Means to collect any leachate, particularly from organic material. Consider sloped concrete floor leading to isolated drainage system Need for gas extraction and collection system and for heat removal systems.
Monitoring	Routine monitoring of storage facility Monitor leachate Leakage detection system - alarm system in case of release of activity.
Waste conditioning	Does waste need to be conditioned prior to storage? Will storage of waste in natural form compromise future disposal e.g. grass decomposition? Unconditioned organic waste may generate methane and carbon dioxide and reactions involving metals will generate hydrogen. All these gases could contain traces of radionuclides and lead to exposures to workers and members of the public.
Type of storage site/facility used	Ease of decontaminating storage facility after use or how any residual contamination will be managed.
Incident response	Risks of integrity of storage facility being breached (e.g. fire/ incident involving radioactive waste material) and plan accordingly.
Location of storage facility	Natural hazards that could affect integrity of stored waste (e.g. flooding).
Radiation protection	Protection of workers, personal monitoring and other equipment Requirements for controlled access.
Security	Controls needed to manage acts of vandalism, terrorist attacks and other threats.
Transport	Access to site, transport routes, proximity to final disposal facility and other aspects.

C2.1 Management options for organic waste

Organic waste from an inhabited area may include grass or turf which has been removed from a lawn, or trees and shrubs (prunings and whole plants) removed from gardens and park areas. Large quantities of organic waste could potentially be generated and the activity in the waste may be high. Furthermore, leaves may have high activity concentrations immediately after dry deposition. Reduction in waste volumes can therefore be very important. It is also necessary to stabilise the waste due its organic nature.

Depending on the level of contamination, a number of methods may be considered to treat the contaminated biomass. For example, aerobic degradation (composting) produces material that may be useful for fertilisation of soil, whereas anaerobic degradation produces gas that may be used in energy production. If an existing composting facility is used or a new facility developed, the run-off of radioactive liquid from the composted waste and its management need to be considered. Core wood from contaminated trees may be applied in industry (e.g. to make furniture) particularly in the early period after an accident where the contamination is likely to be largely confined to the outer surface.

C2.2 Other waste management options

Two other waste management options which may be appropriate in special circumstances are the storage of material which retains contamination well and the reapplication on a road of new hot asphalt mixed with granulated asphalt waste from a road surface.

An example of a material which retains contamination well is roof tiles. Roof tiles are particularly effective in retaining deposited caesium ions; it may take many years for weathering to halve the caesium level. Therefore, storage of such materials in a restricted area will present only a minimal risk of the contamination migrating into the surrounding soil.

The dilution of contaminated asphalt from a road surface with new asphalt together with the shielding provided by the new material mean that the radiation from a road paved with this mixture is likely to be lower than that from the road following planing. This is because virtually all the remaining contamination after planing would have remained on top of the surface. Before this technique is applied, it should be carefully assessed whether enough new asphalt is available to dilute the contamination sufficiently. In addition, the general public may not find the reapplication of contaminated material acceptable, despite its dilution.

C3 WASTE MANAGEMENT OPTIONS FOR LIQUID WASTE ARISING FROM CLEAN-UP

Table 6.15 identifies some management options that give rise to liquid waste which could be contaminated. Before implementing these options, a decision should be made between disposing directly to the sewage system and collecting the waste for storage. It should be noted that storage of large quantities of liquid waste is not likely to be practicable. If the contaminated run-off is allowed to enter the sewer system, an authorisation will be required. In this case, as part of the authorisation it would be necessary to estimate doses to sewage treatment plant workers, potential doses to members of the public and the levels of other contaminants in the water, such as detergents.

Factors to consider for waste water collection and disposal of waste water directly to the sewage system are given in Table C2 and Table C3, respectively.

Table C2 Factors to consider for collection of waste water

Task	Factors to consider
Collection of waste water	How waste water and decontamination products can be collected or contained. Is this practicable for buildings? How to control waste water that normally goes directly to soak-aways (e.g. from roofs). How and where collected waste water can be stored prior to disposal.
Treatment of waste water	How to minimise the volume of waste water as a result of clean-up. Consider separation of contamination via filtering, ion-exchange and other methods. Can this type of treatment be done in local sewage treatment plants? Can treatment be added to normal systems at a local level? Would special facilities be required? Is the option available at nuclear sites? Can treated water be re-used for other clean-up options requiring water (e.g. sandblasting)?
Disposal	Are there options other than sewage plants? It may be worth exploring if nuclear site effluent routes could be used

Table C3 Factors to consider for the disposal of waste water

Issue	Factors to consider
Environmental impact	Control of discharges to sewage system: bypass of sewage treatment works during storm events should be avoided as control of contaminated waste will be lost. Doses to workers and management of sewage by-products also need to be controlled.
Monitoring	The monitoring of waste water needs to be undertaken to assess radiological consequences and to demonstrate control and compliance with any authorisations.
Doses to workers and public	Risk assessments need to be undertaken for people implementing any clean-up options in sewerage systems. Doses should also be assessed for people working in sewage treatment plants handling contaminated waste water. Disposal into rivers may result in doses to public and it may be necessary to consider restrictions on swimming, fishing, including commercial fish farming, and extracting drinking water downstream for a certain period. Sewage sludge could be retained of for longer than normal before incineration or land spreading in order to minimise public doses.
Acceptability	Two way communications with stakeholders will help to find the most acceptable solution. Even if impact is assessed as being small, perceived lack of control of waste water and deliberate contamination of sewage plants and environment may not be acceptable to the public Dilution of contamination in the environment by disposing of contaminated waste water from clean-up of contaminated areas via the sewage system may be favoured. However, this may be very hard to 'sell' to stakeholders.

C4 SEWERS AND SEWAGE TREATMENT SYSTEMS AND DISPOSAL OPTIONS FOR SLUDGE

The radionuclides in contaminated waste water are either in solution or adsorbed to suspended solids and the distribution between these two phases depend on the radionuclides involved. Sewage treatment plants typically use a combination of physical and biological methods to treat waste water. During the treatment, radionuclides are partitioned into sewage effluents and sewage sludge. Disposal options for sewage sludge are described in Table C4. Effluent disposal routes are likely to include discharge to rivers or directly to sea.

Radioactive decay and sorption on walls of the sewers during transit has little effect on the overall activity entering the sewage treatment plant. Radioactive decay during the treatment of sewage sludge will only be significant for short-lived radionuclides. Radionuclides are found in both the solid and effluent phases of the waste. The removal of radionuclides in sewage sludge depends on the general chemistry of the element and the chemical and biological compound that the radionuclides are associated with when disposed. The transfer of radionuclides from sewage to the sewage sludge occurs mainly within the secondary treatment phase. The partitioning of radionuclides in effluent sewage treatment is expressed in terms of a removal coefficient, which is the fraction of the radionuclide remaining in the effluent after a sewage treatment phase. A removal coefficient of 1 implies that all of the activity remains in the effluent and none is transferred to the sludge. Table C5 gives the removal coefficients for selected radionuclides. Further information on partitioning can be found in Titley et al, 2000 and Ham et al, 2003.

Table C4 Disposal options for effluent and sludge arising from sewage treatment

Disposal Option	Description
Effluent disposal	Treated liquid effluents are disposed of to rivers or the sea.
Stabilisation of sludge and disposal to landfill	The practice of sending sludge to landfill directly is diminishing, with only about 5% of all landfills receiving sludge. This represents less than 1% of the waste disposed of via this route. Normally the proportion of sludge co-disposed with municipal waste is less than 20% by weight. It is also usually dewatered, so the solid content of the sludge is about 15 - 25%. The disposal of radionuclides to landfill means that in the near future any radionuclides present will be retained in the waste. Most radionuclides will therefore decay in the landfill site.
Incineration of sludge and disposal of ash to landfill	Incineration is an increasingly common way of disposing of dried sludge. During incineration radionuclides are either released to air, from where they disperse and may deposit to the ground, are captured in offgas scrubbers or are retained in the ash. The ash residue left can be substantial (a typical sludge has an ash content of 25 -30 % of dry solids). The ash is normally taken to a landfill site and buried, although some companies are researching more beneficial uses of incinerator ash. Off gas scrubbers may produce slurry which may be returned to earlier parts of the sewage treatment system for treatment.
Land spreading of sludge	The application of sewage sludge to farmland is the most popular single disposal method (around 37% of sludge in Europe is disposed of via this route). The sludge is a rich source of phosphates, and anaerobically digested sludge has considerable quantities of ammoniacal nitrogen. Sludge can be applied either by spreading or by direct injection during ploughing. Land spreading leads to the incorporation of radionuclides in the environment and in foodstuffs. These may then result in the exposure of farmers and the public. The transfer of radionuclides into foodstuffs is dependent on the rate and nature of the application of the sludge to the land and the subsequent use of the land (in particular crop type and time of harvesting relative to the application of sludge). Sludge is usually only spread onto land once or twice annually (in intervening times it is stockpiled centrally or on farms). There is therefore usually a period during which radionuclides decay prior to its use. This will significantly reduce contamination of the soil and doses to farmers for short-lived radionuclides.

Table C5 Removal coefficients for typical secondary treatment[a]

Radionuclide	Bq/m^3 in effluent per Bq/m^3 entering sewers
^{60}Co	0.2
^{90}Sr	0.9
^{131}I	0.8
^{241}Am	0.8

a) The transfer of radionuclides from sewage to the sewage sludge occurs mainly within the secondary treatment phase

C5 DOSES FROM WASTE MANAGEMENT OPTIONS

C5.1 Doses from management of contaminated refuse

Table C6 provides hourly dose rates to workers managing refuse. The dose rates were calculated for the following tasks:

- handling and collection of waste bags and transfer to refuse lorries.
- travelling in refuse vehicle to waste transfer station.
- handling of waste at transfer station.
- handling of waste at sorting facility.
- incinerator maintenance by engineers.
- transport of incinerator ash to landfill.
- disposal operations at landfill sites by bulldozer or compactor.
- composting operations at composting facility.

Dose rates were estimated for ^{90}Sr, ^{131}I, ^{137}Cs and ^{239}Pu, based on assumptions from Harvey et al, 1995, but ignoring allowance for any mixing with uncontaminated refuse. The exposure pathways considered were external exposure, inhalation of resuspended dust and external skin dose from ash dust. Doses from skin contact with contaminated material were not estimated for refuse workers as it was assumed that they would wear gloves and suitable clothing. The dose rates given in Table C6 apply only to the period when workers are handling contaminated material and are normalised to the contamination levels in the waste being managed at the point the task is undertaken. It should be remembered that the contaminated refuse may be mixed with uncontaminated refuse at some of these stages, resulting in a lower activity concentration in the managed material.

It is important to note that the majority of these doses are only likely to be received in the short term. This emphasises the importance of having a monitoring scheme in place for measuring contamination levels in the refuse and garden waste, preferably at a number of stages.

Dose rates in Table C6 should be used for scoping calculations only and to help identify that tasks that give rise to the highest doses. Actual dose rates depend on the specific situation and the use of estimated values, such as those given in the table, should not replace a detailed assessment of doses to the workers.

Doses to the public may arise following disposal of contaminated refuse via incineration, landfill and composting. The main processes and potential exposure pathways to members of the public that may occur are listed in Table C7. In the event of a radiological emergency, it will be necessary to undertake a full assessment (including the assessment of potential doses to members of the public) if existing legal authorisations are changed, or if new disposal sites or other disposal or storage options are authorised.

Table C6 Doses to people working with contaminated refuse

	Dose rates per unit activity concentration waste handled (Sv h^{-1} Bq^{-1} kg)			
Task	^{90}Sr (+^{90}Y)	^{131}I*	^{137}Cs#	^{239}Pu†
Refuse collection	8 10^{-13}	1 10^{-11}	2 10^{-11}	5 10^{-11}
Refuse vehicle	1 10^{-12}	2 10^{-11}	3 10^{-11}	5 10^{-11}
Transfer station	1 10^{-12}	2 10^{-11}	3 10^{-11}	5 10^{-11}
Sorting facility	4 10^{-12}	3 10^{-12}	4 10^{-12}	5 10^{-11}
Municipal incinerator	7 10^{-13}	3 10^{-14}	4 10^{-13}	1 10^{-9}
Secondary transport (incineration)	1 10^{-11}	4 10^{-12}	1 10^{-10}	2 10^{-15}
Landfill operations	1 10^{-11}	3 10^{-10}	5 10^{-10}	4 10^{-11}
Composting facility‡	8 10^{-12}	3 10^{-10}	4 10^{-10}	1 10^{-10}

Notes:

*: Can be used for ^{99}Mo, ^{132}Te, ^{136}Cs, ^{140}La, ^{140}Ba, ^{169}Yb

#: Can be used for ^{60}Co, ^{75}Se, ^{95}Zr, ^{95}Nb, ^{103}Ru, ^{106}Ru, ^{134}Cs, ^{144}Ce, ^{192}Ir, ^{235}U, ^{226}Ra

†: Can be used for ^{238}Pu, ^{241}Am

‡: Composting may take from a few weeks up to 2 to 3 months. Operators may be exposed over these timescales, even if new waste entering the plant is no longer contaminated.

Table C7 Potential exposure pathways for members of the public following disposal of contaminated refuse

Disposal process	Potential exposure pathways
Stack discharges from incineration	People living downwind of incinerator: external dose and inhalation of resuspended material following deposition. Note that most radionuclides, notably excluding ^{131}I, are trapped in the incinerator filters and are not released to atmosphere. Ingestion of food grown on contaminated land
Landfill	People using closed landfill sites for recreation (e.g. walking dogs): external dose and inhalation of dust. Long-term migration of radionuclides through soil: external dose and inhalation of resuspended material from contaminated soil, ingestion of food grown on contaminated soil. Future use of closed landfill for building: external dose and inhalation of resuspended material from contaminated land, ingestion of food grown on contaminated land.
Use of composted material on land (commercial and domestic)	Application of compost: external dose and inhalation of dust; ingestion of food grown on contaminated land; possible skin dose to hands.

C5.2 Doses from sewage treatment and disposal

Indicative dose rates for workers at sewage treatment plant have been estimated for a selection of the radionuclides considered in the Handbook: ^{90}Sr, ^{131}I, ^{60}Co and ^{241}Am (Harvey et al, 1995, Titley et al, 2000). These radionuclides should be taken as being illustrative of strong[1] beta emitters (^{90}Sr, and its daughter ^{90}Y), short–lived high energy beta/gamma emitters (^{131}I), long-lived high energy beta/gamma emitters (^{60}Co) and alpha emitters (^{241}Am). The dose rates are presented in Table C8 and are generally applicable to UK sewage treatment plants servicing small towns. For large sewage treatment plants, doses to workers involved in all activities except maintenance of sewer pipes are likely to be significantly lower (they could be assumed to be a factor of 10 lower). Doses to workers at sewage treatment plants may generally vary depending on the time they spend during each task, the size of the plant and the procedures used. However, it is unlikely that doses to these workers vary significantly across different treatment plants. Exposure pathways considered in the calculation of the dose rates presented in Table C8 are external exposure, inhalation of resuspended material; shielding was not taken into account. The types of worker considered were:

- sewer pipe workers who spend most of the time checking and unblocking the main sewers
- general sewer workers undertaking tasks around a plant adopting sludge stabilisation prior to disposal
- general sewer workers undertaking tasks around a plant adopting sludge incineration
- sludge press workers working in the sludge press room near incinerators
- workers at landfill site where sludge is disposed.

Doses to members of the public from disposal of radionuclides depend on the final disposal routes of the effluent and the sludge. Effluents can be disposed of to rivers or the sea while sludge can be disposed of to landfill and agricultural land and through incineration. Methodologies which can be used to calculate doses to members of the public are described in Chen et al, 2007 (sludge to landfill), Mobbs et al, 2005 (sludge to farmland) and Titley et al, 2000 (all other disposal routes).

If calculation of dose based on generic methodologies suggest that doses to workers or members of the public may be of concern, it is important to take into account details of the specific procedures used in the sewage treatment plants in the area and the habits of workers and the population. The main factors that need to be taken into account are listed in Table C9. For long-lived radionuclides, long-term contamination and doses to workers at the sewage treatment plant also needs to be considered. Persistence of contamination in the systems and the effectiveness of any normal cleaning practices will need to be taken into account.

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[1] For the purposes of the Handbook, a strong beta emitter is defined as having a maximum beta energy higher than 2 MeV.

Table C8 Indicative dose rates to workers involved in sewage treatment and disposal

	Dose rates per unit activity concentration in the water entering sewage treatment plant (Sv h^{-1} Bq^{-1} m^3)			
Radionuclide	^{60}Co*	^{90}Sr	^{131}I$^{\#}$	^{241}Am^{+}
Sewer pipe worker	6 10^{-12}	7 10^{-15}	4.10^{-13}	8 10^{-13}
General worker (sludge stabilisation)	7 10^{-9}	4 10^{-13}	2 10^{-10}	4 10^{-10}
General worker (sludge incineration)	2 10^{-8}	2 10^{-12}	3 10^{-10}	3 10^{-10}
Sludge press worker (sludge incineration)	4 10^{-9}	5 10^{-13}	1 10^{-10}	9 10^{-10}
Landfill worker (incinerated ash)	1 10^{-10}	8 10^{-14}	3 10^{-13}	5 10^{-14}

Notes:

* Values for ^{60}Co can also be used for ^{75}Se, ^{95}Zr, ^{95}Nb, ^{103}Ru, ^{106}Ru, ^{134}Cs, ^{144}Ce, ^{192}Ir, ^{235}U and ^{226}Ra

$^{\#}$ Values for ^{131}I can also be used for ^{99}Mo, ^{132}Te, ^{136}Cs, ^{140}La, ^{140}Ba, ^{169}Yb

$^{+}$ Values for ^{241}Am can also be used for ^{238}Pu and ^{239}Pu.

Table C9 Site specific information needed for detailed dose assessment

Information required	Details
Type of sewer system	Combined, separate or mixed
Capacity of sewer and water treatment plant	Sewer size (diameter), sewer flow rate
Aquatic environment that treated or untreated waste water is discharged into:	Volumetric flow rate, width, depth, usage of river water, salinity
Treatment processes of sewage effluent and sewage sludge	What processes are in operation
Discharge route of waste streams from sewage treatment works	Sewage application rates to farmland, weather conditions at incinerator

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APPENDIX D

Practical recommendations for engaging with stakeholders in the management of contaminated areas

In recent years, stakeholder issues have moved steadily to the forefront of policy decisions and are key to the development and implementation of radiological protection strategies. As experience in stakeholder engagement has grown, it has been possible to use many of the lessons learned as a basis for the development of best practice among the radiological protection community. Processes and tools are becoming established that can be generally applied to situations where the input and views of stakeholders are required. The process of engaging with stakeholders involves five distinct steps which follow a logical sequence: preparation, planning, engagement, evaluation and application. Each of these steps is described below. The International Radiation Protection Association (IRPA, 2008) has issued further guidance in its ten guiding principles that should also be considered by radiation protection professionals when engaging with stakeholders. These principles are summarised in Table D1.

Table D1 IRPA Guiding principles on stakeholder engagement (IRPA, 2008)

	Principles
1	Identify opportunities for engagement and ensure the level of engagement is proportionate to the nature of the radiation protection issues and their context
2	Initiate the process as early as possible, and develop a sustainable implementation plan
3	Enable an open, inclusive and transparent stakeholder engagement process
4	Seek out and involve relevant stakeholders and experts
5	Ensure that the roles and responsibilities of all participants and the rules for cooperation are clearly defined
6	Collectively develop objectives for the stakeholder engagement process, based on a shared understanding of issues and boundaries
7	Develop a culture which values a shared language and understanding, and favours collective learning
8	Respect and value the expression of different perspectives
9	Ensure a regular feedback mechanism is in place to inform and improve current and future stakeholder engagement processes
10	Apply the IRPA Code of Ethics in their actions within these processes to the best of their knowledge

D1 STEPS FOR SUCCESS STAKEHOLDER ENGAGEMENT

D1.1 Preparation

Opportunities for proactive engagement need to be identified by developing a good understanding of the issues at stake. The method of engagement should be proportionate to these issues and their context, bearing in mind that there will be resource if not time constraints. The appointment of a leader who is well respected and a good communicator is important. The leader and his/her team can be independent, or selected from central Government departments and agencies, or from local authorities. They should aim to seek out and involve a wide range of stakeholders as all aspects of life need to be considered when undertaking the sustainable management of contaminated areas.

D1.2 Planning

The engagement should be initiated as early as possible and requires the development of a sustainable plan. The engagement could be a one-off process but is more likely to be implemented over an extended period in contaminated areas to build a common understanding and shared vision of how to manage the area. Planning involves establishing the objectives, scope, format and mode of engagement, the identification of potential stakeholders and the design of the engagement i.e. agendas and meeting logistics including any rules to be applied.

D1.3 Engagement

At the start of the engagement, the roles, responsibilities and accountabilities of all participants should be established. Openness, inclusiveness and transparency, which are interrelated, should constitute the essence of a successful engagement and should be present throughout the process. It is important to share the relevant information needed to build a collective understanding of the issues. The information should be presented in a simple non-scientific language. It should be concise, clear to all and honest. Each stakeholder needs to recognise their own and each others' uniqueness and to be aware that other participants may view issues from different perspectives and to respect this. The acceptance of diverse perspectives, thinking and values has the potential to enrich the process, providing that the process is controlled such that any entrenched views and ideologies, if present, are managed by agreed mechanisms.

D1.4 Evaluation

When engaging with stakeholders an opportunity should be provided for both the stakeholders and those responsible for the process to give mutual feedback on the approaches and tools used and on eventual outcomes. This serves to inform and improve ongoing processes as well as influencing how future ventures should be conducted. The following types of criteria can be evaluated: appropriateness of the terms and timing of engagement, the quality and appropriateness of the information provided; comprehensiveness of the issues that were addressed; inclusivity of the stakeholders involved; practicability/feasibility of the eventual outcomes.

D1.5 Application

When a stakeholder engagement process comes to an end, it is important that those responsible for the process make the results known to all those who participated. If these results do not reflect the recommendations/findings from the stakeholders, those responsible must offer an explanation to the stakeholders for any deviation from what was agreed. In this way, the feedback of results and decisions will help to maintain confidence in the process.

D2 REFERENCES

International Radiation Protection Association (2008). Guiding Principles for Radiation Protection Professionals on Stakeholder Engagement. IRPA 08/08. Available from http://www.irpa.net

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Table 6.2 Selection table of management options for buildings

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Permanent relocation from residential areas (8)	▦	▦
Prohibit public access to non-residential areas (9)	░	▦
Restrict workforce access (time or personnel to non-residential areas (10)	░	▦
Temporary relocation (11)	░	▦
External surfaces		
Demolish buildings (12)	▦	▦
Firehosing (13)	⬜	■
High pressure hosing (14)	■	■
Peelable coatings (49)	░	■
Mechanical abrasion of wooden walls (15)	░	■
Roof brushing (16)	░	░
Roof cleaning with pressurised hot water (17)	░	░
Roof replacement (18)	▦	▦
Sandblasting (19)	■	■
Snow removal (50)	░	■
Tie down (fixing contamination to the surface) (20)	░	■
Treatment of walls with ammonium nitrate (21)	░	■
Indoor surfaces and objects		
Other cleaning methods (scrubbing, shampoo, steam cleaning) (23)	⬜	■
Removal of furniture, soft furnishings and other objects (24)	░	░
Surface removal (25)	░	░
Vacuum cleaning (26)	⬜	⬜
Washing (27)	⬜	■
Public buildings (e.g. railway stations)		
Aggressive cleaning of indoor contaminated surfaces (22)	░	░
Precious objects and personal items		
Storage, shielding, covering, gentle cleaning of precious objects (28)	⬜	▦
Specialised surfaces in industrial buildings		
Application of detachable polymer paste on metal surfaces (53)	⬜	■
Chemical cleaning of metal surfaces (54)	░	■
Chemical cleaning of plastic and coated surfaces (55)	░	■
Cleaning of contaminated (industrial) ventilation systems (56)	░	░
Electrochemical cleaning of metal surfaces (57)	░	■
Filter removal (58)	⬜	⬜
Ultrasound treatment with chemical decontamination (59)	░	■

Key:

⬜	Recommended with few constraints
░	Recommended but requires further evaluation to overcome some constraints
▦	Economic or social constraints exist, requiring full analysis and consultation period.
■	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

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Table 6.3 Selection table of management options for roads and paved areas

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Permanent relocation from residential areas (8)	▦	▦
Prohibit public access to non-residential areas (9)	░	▦
Restrict workforce access (time or personnel to non-residential areas (10)	░	▦
Temporary relocation (11)	░	▦
Removal and shielding options		
Firehosing (29)	⬜	■
High pressure hosing (30)	░	░
Snow removal (50)	░	■
Surface removal and replacement (31)	■	░
Tie down (fixing contamination to the surface) – bitumen (permanent) (32)	░	▦
Tie down (fixing contamination to the surface) – sand (temporary) (32)	⬜	■
Tie down (fixing contamination to the surface) – water (temporary) (32)	⬜	■
Turning paving slabs (33)	░	░
Vacuum sweeping (34)	⬜	■

Key:

⬜	Recommended with few constraints
░	Recommended but requires further evaluation to overcome some constraints
▦	Economic or social constraints exist, requiring full analysis and consultation period
■	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

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Table 6.4 Selection table of management options for soils, grass and plants

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Permanent relocation from residential areas (8)	▦	▦
Prohibit public access to non-residential areas (9)	░	▦
Restrict workforce access (time or personnel to non-residential areas (10)	░	▦
Temporary relocation (11)	░	▦
All open spaces		
Cover grassed and soil surfaces (e.g. with asphalt) (35)	▦	▦
Cover with clean soil (36)	░	░
Grass cutting and removal (38)	□	■
Plant and shrub removal (40)	░	■
Snow removal (50)	░	■
Tie-down (fixing contamination to the surface) (44)	▦	■
Topsoil and turf removal (manual) (45)	■	▦
Topsoil and turf removal (mechanical) (46)	■	▦
Turf harvesting (48)	░	░
Small open spaces (e.g. gardens)		
Manual digging (39)	░	░
Rotovating (mechanical digging) (42)	░	░
Triple digging (47)	■	■
Large open spaces (e.g. parks, countryside)		
Deep ploughing (37)	░	░
Ploughing (41)	□	□
Skim and burial ploughing (43)	■	░

Key:

□	Recommended with few constraints
░	Recommended but requires further evaluation to overcome some constraints
▦	Economic or social constraints exist, requiring full analysis and consultation period.
■	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

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Table 6.5 Selection table of management options for trees and shrubs

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Permanent relocation from residential areas (8)	▦	▦
Prohibit public access to non-residential areas (9)	▒	▦
Restrict workforce access (time or personnel to non-residential areas (10)	▒	▦
Temporary relocation (11)	▒	▦
Removal options		
Collection of leaves (51)	□	■
Tree and shrub pruning/removal (52)	■	■

Key:

□	Recommended with few constraints
▒	Recommended but requires further evaluation to overcome some constraints
▦	Economic or social constraints exist, requiring full analysis and consultation period
■	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to colour table

Table 7.2 Selection table of management options for soils, grass and plants

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Permanent relocation from residential areas (8)	▦	▦
Prohibit public access to non-residential areas (9)	▒	▦
Restrict workforce access (time or personnel to non-residential areas (10)	▒	▦
Temporary relocation from residential areas (11)*	▒	▦
All open spaces		
Cover grassed and soil surfaces (e.g. with asphalt) (35)	▦	▦
Cover with clean soil (36)	▒	▒
Grass cutting and removal (38)	□	■
Plant and shrub removal (40)	▒	■
Snow removal (50)	▒	■
Tie-down (fixing contamination to the surface) (44)	▦	■
Topsoil and turf removal (manual) (45)	■	▦
Topsoil and turf removal (mechanical) (46)	■	▦
Turf harvesting (48)	▒	▒
Small open spaces (e.g. gardens)		
Manual digging (39)	▒	▒
Rotovating (mechanical digging) (42)	▒	▒
Triple digging (47)	■	■
Large open spaces (e.g. parks, countryside)		
Deep ploughing (37)	▒	▒
Ploughing (41)	□	□
Skim and burial ploughing (43)	■	▒

□	Recommended with few constraints
▒	Recommended but requires further evaluation to overcome some constraints
▦	Economic or social constraints exist, requiring full analysis and consultation period.
■	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Notes:

* Only while options in garden are being implemented.

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Table 7.3 Selection table of management options for soils, grass and plants

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months – years)
Restrict access		
Temporary relocation from residential areas (11)*	░	▩
All open spaces		
Cover grassed and soil surfaces (e.g. with asphalt) (35)	▩	▩
Cover with clean soil (36)	░	░
Grass cutting and removal (38)	□	■
Plant and shrub removal (40)	░	
Tie-down (fixing contamination to the surface) (44)	▩	
Topsoil and turf removal (manual) (45)	■	▩
Topsoil and turf removal (mechanical) (46)		
Turf harvesting (48)	░	░
Small open spaces (e.g. gardens)		
Manual digging (39)	░	░
Rotovating (mechanical digging) (42)	░	░
Triple digging (47)	■	

□	Recommended with few constraints
░	Recommended but requires further analysis to overcome some constraints
▩	Economic or social constraints exist, requiring full analysis and consultation period.
■	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Notes:

* Only while options in garden are being implemented.

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Table 7.6 Selection table of management options for soils, grass and plants

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months – years)
Restrict access		
Temporary relocation from residential areas (11)*	░	▦
All open spaces		
Grass cutting and removal (38)	□	■
Plant and shrub removal (40)	░	■
Topsoil and turf removal (manual) (45)	■	▦
Topsoil and turf removal (mechanical) (46)	■	▦
Small open spaces (e.g. gardens)		
Manual digging (39)	░	░
Rotovating (mechanical digging) (42)	░	░

□	Recommended with few constraints
░	Recommended but requires further analysis to overcome some constraints
▦	Economic or social constraints exist, requiring full analysis and consultation period.
■	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Notes:

* Only while options in garden are being implemented.

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Table 7.9 Selection table of remaining management options for city gardens

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Temporary relocation from residential areas (11)*		▦
City gardens		
Manual digging (39)	░	░
Rotovating (42)	░	░
Topsoil and turf removal (manual) (45)	■	▦
Topsoil and turf removal (mechanical) (46)		

Key:

	Recommended with few constraints
░	Recommended but requires further analysis to overcome some constraints
▦	Economic or social constraints exist, requiring full analysis and consultation period.
■	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Notes:

* Only while options in garden are being implemented.

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Table 7.11 Selection table of management options for buildings

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Permanent relocation from residential areas (8)	▦	▦
Prohibit public access to non-residential areas (9)	░	▦
Restrict workforce access (time or personnel to non-residential areas (10)	░	▦
Temporary relocation from residential areas (11)*	░	▦
External surfaces		
Demolish buildings (12)	▦	▦
Firehosing (13)	□	■
High pressure hosing (14)	■	■
Peelable coatings (49)	░	■
Mechanical abrasion of wooden walls (15)	□	□
Roof brushing (16)	░	░
Roof cleaning with pressurised hot water (17)	░	░
Roof replacement (18)	▦	▦
Sandblasting (19)	■	■
Snow removal (50)	░	■
Tie down (fixing contamination to the surface) (20)	░	■
Treatment of walls with ammonium nitrate (21)	░	■
Indoor surfaces and objects		
Other cleaning methods (scrubbing, shampoo, steam cleaning) (23)	□	■
Removal of furniture, soft furnishings and other objects (24)	░	░
Surface removal (25)	░	░
Vacuum cleaning (26)	□	□
Washing (27)	□	■
Public buildings (e.g. railway stations)		
Aggressive cleaning of indoor contaminated surfaces (22)	░	░
Precious objects and personal items		
Storage, shielding, covering, gentle cleaning of precious objects (28)	□	▦
Specialised surfaces in industrial buildings		
Application of detachable polymer paste on metal surfaces (53)	□	■
Chemical cleaning of metal surfaces (54)	░	■
Chemical cleaning of plastic and coated surfaces (55)	░	■
Cleaning of contaminated (industrial) ventilation systems (56)	░	░
Electrochemical cleaning of metal surfaces (57)	░	■
Filter removal (58)	□	□
Ultrasound treatment with chemical decontamination (59)	░	■

Key:

□	Recommended with few constraints
░	Recommended but requires further evaluation to overcome some constraints
▦	Economic or social constraints exist, requiring full analysis and consultation period.
■	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

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Table 7.12 Selection table of management options for buildings

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Prohibit public access to non-residential areas (9)	░	▦
External surfaces		
Firehosing (13)	⬜	■
High pressure hosing (14)	■	■
Peelable coatings (49)	░	■
Roof brushing (16)	░	░
Roof cleaning with pressurised hot water (17)	░	░
Roof replacement (18)	▦	▦
Sandblasting (19)	■	■
Treatment of walls with ammonium nitrate (21)	░	■

Key:

⬜	Recommended with few constraints
░	Recommended but requires further analysis to overcome some constraints
▦	Economic or social constraints exist, requiring full analysis and consultation period.
■	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to colour table

Table 7.17 Selection table of management options for external building surfaces

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Prohibit public access to non-residential areas (9)	░	▦
External surfaces		
High pressure hosing (14)	■	■
Peelable coatings (49)	░	■
Roof brushing (16)	░	░
Roof cleaning by pressurised hot water (17)	░	░
Roof replacement (18)	▦	▦
Sandblasting (19)	■	■

Key:

□	Recommended with few constraints
░	Recommended but requires further analysis to overcome some constraints
▦	Economic or social constraints exist, requiring full analysis and consultation period.
■	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis